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Analyzed New Design Data Driven Modelling of Piezoelectric Power Generating System

Solly Aryza[1], Zulkarnain Lubis[2], M. Isa Indrawan[3], Syahril Efendi[4], Poltak Sihombing[5]
[1,3]*Universitas Pembangunan Pancabudi, Indonesia*
[2]*Institute Tekhnologi Medan, Indonesia*
[1,4,5]*Faculty of Computer Science and Information Technology, University ofSumatera, Indonesia*
sollyaryzalubis@gmail.com

Abstract

The piezoelectric speed bumps designed in this study consist of a speed bump mechanical system that functions to receive input from motorized vehicle pressure, piezoelectric cantilever system as a component producing electrical energy and energy harvesting system as energy harvester from piezoelectric material. One system module consists of a piezoelectric parallel circuit connected to the MB39C811 buck converter. In this paper, we will discuss the mechanism for analyzing the design and modeling of a piezoelectric power plant system on a bluff body-based speed bump with a cantilever system for variations in motor vehicle speed by means of physical modeling. In the piezoelectric speed bump in the form of a bluff body, it can be seen that the air flow when passing through the triangular cross section has an increase in speed so that the resulting vortex has a high speed. This is what causes high vibrations in the piezoelectric so that the maximum voltage and the average voltage are the highest. Piezoelectric speed bumps are capable of generating electrical power with an input of 60 times the motorized vehicle track of 2.166mWh with an efficiency of 2.87% compared to manual input.

Keywords
piezoelectric; speed bump; electrical energy; cantilever; bluff body

I. Introduction

The use of electricity in everyday life greatly affects the future.The electricity we use today comes from power plants that use fuel oil, coal, and others. One day the fuel we use will run out. With that we have to create Alternative Energy that can be used in the long term. There are various examples of Alternative energy, as an example that we can apply is Piezo Electric. For example, the use of electricity in a campus environment, we can replace it with piezo electricity. With an example of installing a piezoelectric on a speed bump by utilizing pressure power in the campus road area, installing a Piezoelectric Buzzer as a source of electrical energy in campus garden lights.

Speed bumps or speed bumps themselves are widely available on highways where there is generally a relatively high interaction between humans and motorized vehicles, therefore speed bumps function to slow down the speed of vehicles passing through the road to reduce the risk of accidents. The pressure exerted by motorized vehicles passing through the speed bumps can be used for the business of taking or harvesting electrical energy with the Piezo electric principle.

The word piezoelectric comes from the Latin, piezein which means squeezed or pressed and electric which means electrical energy. So the definition of piezoelectric itself is an energy harvesting device that can convert vibration or pressure energy into electrical energy, so that the piezoelectric effect occurs due to the electric field formed because the material is subjected to mechanical stress.

The use of piezoelectric materials can produce a large enough potential difference so that it is widely used as a source of high and medium voltage. Piezoelectricity has begun to be used in several Asian countries, one of which is in Japan. At this writingdescribes the analysis of piezoelectric development which is focused on making a mechanical system in the form of a speed bump or speed bump which is basically a prominent road with a surface of about 3-5 inches which is usually found in areas that have relatively close interaction between humans and motorized vehicles. One of them is in the campus environment by considering the design and modeling of the harvesting energy system (SBEH) in the form of a bluff body with a cantilever system. By utilizing the pressure or vibration generated by motorized vehicles or cars and even pedestrians passing through campus streets to harvest or produce Piezoelectric alternative energy.

II. Review of Literature

Energy harvesting is a way of collecting energy from a source until it is ready for use as needed. This concept makes it possible to harvest small amounts of energy and collect it during the energy harvesting process. The scheme of the speed bump system is designed as follows:

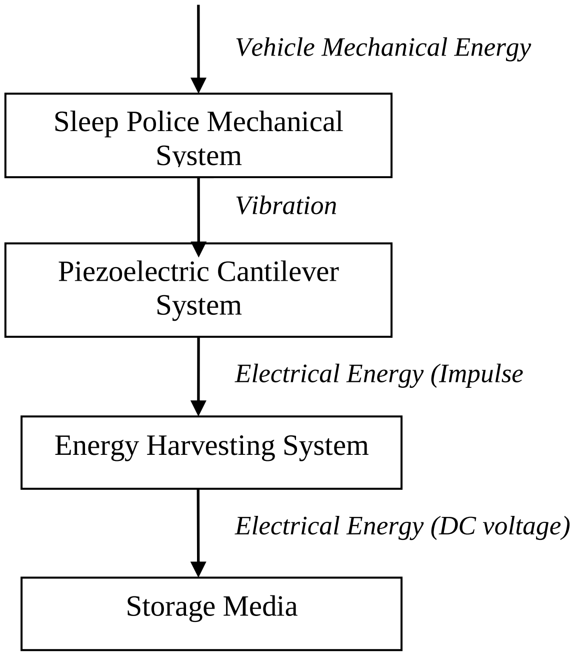

***Figure 1**. Schematic of a Piezoelectric Speed Bump System*

Vehicle tires will put pressure on the piezoelectric speed bump mechanical system and cause a change in mechanical energy into vibrational energy. The vibration energy will be transmitted to the cantilever system, causing the piezoelectric material to deflect and generate an electric voltage. The resulting electrical voltage is in the form of a series of impulse signals that are not in the same direction. Therefore, this signal needs to be rectified with a buck converter such as the MB39C811, while further use to charge the battery requires a charging module.

2.1 Harvesting Energy System

The output voltage of the piezoelectric material in the form of a series of impulse signals cannot be used directly, so an energy harvesting system is needed. Energy harvesting system consists of buck converter, charging module and storage media. Buck converter is a module that functions to convert a DC voltage into a lower DC voltage that has a certain voltage and current. Buck converter is needed to make the input voltage in the form of an impulse into a more continuous DC voltage. One of the buck converters that can be used is the MB39C811. MB39C811 is an integrated circuit consisting of a full-wave bridge rectifier with low power loss. MB39C811 can be applied to harvest energy from piezoelectric which has a small current.

2.2 Modeling Speed Bump Energy Harvester (SBEH)

The motion response equation to the impulse can be applied to the speed bump by using the Speed Bump Energy Harvester (SBEH) model. This is because the speed bump gets a momentary impulse when passed by the vehicle. For a very short period of time, referring to the dynamics of the speed bump, we can see that the impulse can be calculated by finding the change in momentum of the speed bump as a result of the load by the vehicle passing through the speed bump. When the vehicle is passing through the SBEH, the interaction between the vehicle and the SBEH is much more complex due to the interactive boundary conditions moving between the tire and the speed profile cover speed bump. The center of gravity of the car can be found by weighing the pressure of the front and rear wheels. After that, by lifting the rear wheel of the vehicle using a jack, then the slope angle will be obtained which will later be used to determine the height of the center of gravity of the wheel axle (hr). The vehicle compressive force is used to determine the load received by the speed bump when the vehicle passes.

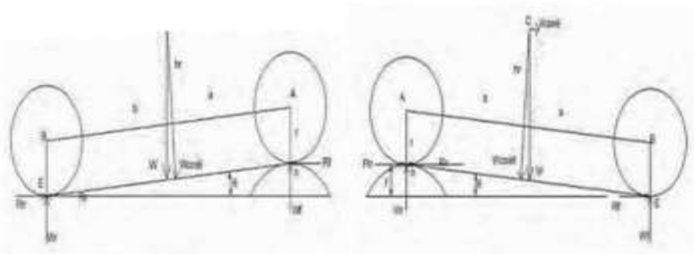

Figure 2. *Model of the interaction between SBEH and the front and rear wheels of the vehicle*

When the vehicle interacts with the SBEH model, the weight of the vehicle applied to the speed bump cover will move vertically downwards. The magnitude of the vehicle wheel compression force can be analyzed by the equation:

$$Wf = \frac{W(hr+r).\sin\emptyset + W.b.\cos\emptyset + Rf.\cos\emptyset}{(a+b).\sin\emptyset} \text{ (Front wheel) } \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{ (1)}$$

$$Wr = \frac{W.a.\cos\emptyset - W(hr+r).\sin\emptyset - Ftr.\cos\emptyset.y + Rr.\cos\emptyset.y}{(a+b).\sin\emptyset} \text{ (Rear wheel) } \ldots\ldots\ldots\ldots\ldots\ldots \text{ (2)}$$

With:

wf/r = front/rear wheel pressure (N)

Rf/r = front/rear wheel rolling resistance (N)

Y = speed bump track height (m)

W = total weight of the vehicle (N)
Ftr = vehicle thrust on rear wheels (N)
a = distance from the center of gravity of the vehicle to the front axle (m)
b = distance from the center of gravity of the vehicle to the rear axle (m).
□ = tilt angle
hr = height of center of gravity of wheel axle

Meanwhile, the equation for the down-speed response for the speed bump to the vehicle's compressive force is given by the following equation:

……………………………………………(3)$\dot{x}(t) = \frac{Ie^{-\varepsilon\omega_n t}}{m\omega_d}\left(-\varepsilon\omega_n \sin\omega_d t + \omega_d \cos\omega_d t\right)$

Where:
I = impulse
m = mass of vehicles and drivers,
n = natural frequency of the system
d = attenuation frequency and
ε = is the damping ratio.

2.3. Piezoelectric & Vibration

Piezoelectric is defined as a material that can produce an electric voltage when subjected to stress or strain. When there is stress or strain on the surface of the piezoelectric material, the movement of electrons becomes unidirectional and polarized. This causes the occurrence of positive and negative charges on the surface of the material so that an electric voltage arises. Based on the energy harvesting scheme of the mass spring system in Figure 1, the damping (b), mass (m) and spring constant (k) have a relationship with changes in sinusoidal motion. The natural frequency vibration is given by the equation so that the sinusoidal equation is$\omega_n = \sqrt{k/m} z(t) = A\sin(\omega_n t)$ Maximum electric power can be generated at high kinetic energy, low resonant frequency and low damping energy level. The vibration properties for the cantilever system are the same as for the mass-spring system so that the equation is obtained; [7]

$m_{eq} = 0{,}23\rho\,(W.L.T) + m$ ……………………………………………………………… (1)

$k_{eq} = \frac{3YI}{L^3} = \frac{YWT^3}{4L^3}$ …………………………………………………………………………(2)

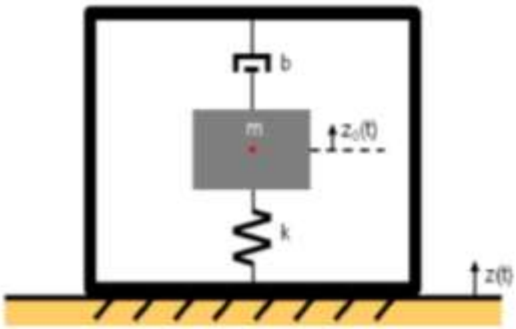

Figure 3. *Model of spring-mass system energy harvester*

,W,L,T,Y,I, □sequentially are mass density, width, length, thickness, Young's modulus, moment of inertia and stiffness. When the plate is bent there will be strain and stress. In the case where the strain is small, some materials ignore Hooke's law so that the stress is proportional to the strain where the proportionality constant becomes Young's modulus, (□=□).

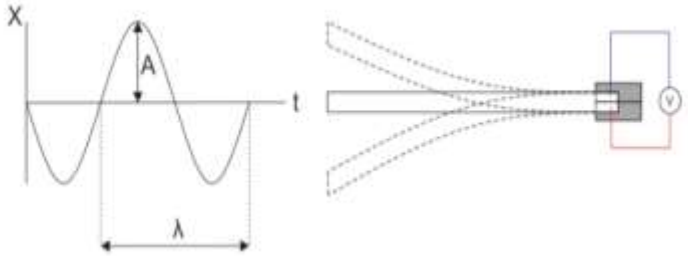

Figure 4. *Piezoelectric simple harmonic motion of a cantilever system*

Harmonic motion is the back and forth motion of an object through a certain equilibrium point with the number of vibrations of the object in every second is always constant. The simplest form of periodic motion is harmonic motion. This can be demonstrated by a mass suspended from a cantilever system as shown in Figure 2. If the mass is removed from rest and released, the mass will oscillate up and down.

III. Research Methods

3.1. Piezoelectric Speed Bump System Modeling

In contrast to conventional speed bumps which provide a fixed height profile, this speed bump-based power plant design can move up and down and interact dynamically with passing vehicles. By modifying the speed bump so that it can change the kinetic and potential energy of the speed bump then it is converted into electrical energy when driving the generator when the vehicle crosses the speed bump. To simplify the analysis, it is assumed that the vehicle passing the speed bump has a constant speed, thus the horizontal speed of the tire is the same as the speed of the vehicle. The vehicle speed is constant when the vehicle passes the speed bump, namely 5 km/hour, 10 km/hour and 15 km/hour.

A piezoelectric speed bump modeling system can be modeled in a spring mass system. This modeling can be derived into a mathematical equation to observe the parameters that affect the piezoelectric output voltage which is expressed as follows:

$$F(t) = k_{sk}(x_{sk} - x_k) + b_{sk}(\dot{x}_{sk} - \dot{x}_k) + m_{sk}\ddot{x}_{sk} \quad (3)$$

$$0 = k_k(x_k - x_z) + b_k(\dot{x}_k - \dot{x}_z) + m_k\ddot{x}_k \quad (4)$$

$$0 = k_z x_z + b_z \dot{x}_z + m_z \ddot{x}_z \quad (5)$$

In electrical modeling, it can be modeled by equation (6) which shows the relationship between the deflection of the piezoelectric and the resulting voltage

$$I(t) = I_{Cz} + I_{Rz} \quad (6)$$

$$V_z = KR_z\dot{x}_z - R_z C_z \dot{V}_z \quad (7)$$

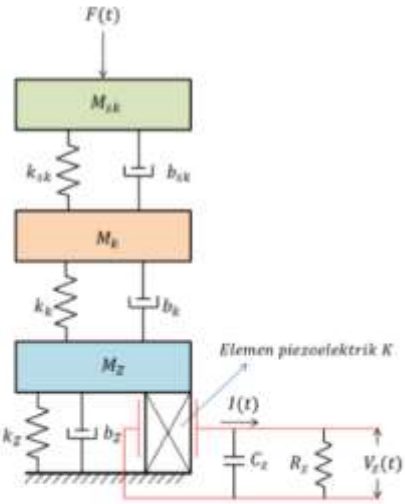

Figure 5. *Modeling a piezoelectric cantilever system*

Based on the modeling, it can be observed that the parameters that affect the piezoelectric output voltage are the size of the piezoelectric deflection or change ($\dot{X}_z$). The greater the change in piezoelectric deflection, the greater the output current and voltage. The piezoelectric change () is influenced by the KSK, bsk, msk, kk, and mk factors. This parameter is a parameter that can be changed according to the choice of material when manufacturing a piezoelectric cantilever system. Selection of the right material is needed to be able to produce optimal piezoelectric deflection. Other parameters such as kz , bz , mr , Rz , and Cz are fixed parameters according to the type of piezoelectric used.$\dot{X}_z$

3.2. Piezoelectric Speed Bump System Design

The design of the speed bump system that has been carried out includes the design of the cantilever, the mechanical speed bump system, and the design of the spring and the design by measuring the average electric voltage and the maximum electrical voltage generated by the piezoelectric cantilever system in air flow without a bluff body, passing through a triangular bluff body and circle. The distance between the piezoelectric and the bluff body used in this study was 50 and 100 mm. The design of the cantilever is done by testing the cantilever with input in the form of a shaker with a frequency of 6 Hz using a piezoelectric Kinez K7520BP2. The piezoelectric material K7520BP2 is affixed directly to the cantilever which is made of 0.25mm thick stainless steel and 160mm long from the clamp point. The tests carried out include the configuration of the piezoelectric circuit, piezoelectric position on the cantilever and determination of the maximum deflection of the cantilever. Testing the piezoelectric configuration is carried out in two ways, namely piezoelectric in parallel and in series. The next test is the position of the piezoelectric material on the cantilever. This test is intended to determine the most optimal position of the piezoelectric to the cantilever.

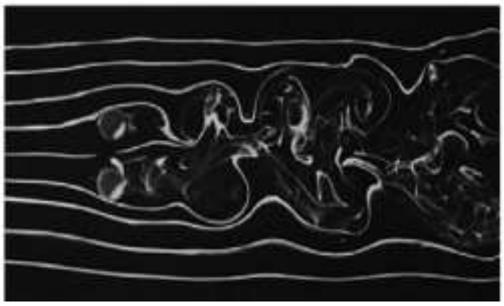

Figure 6. *Vortex phenomenon when air passes through a cylindrical cross section*

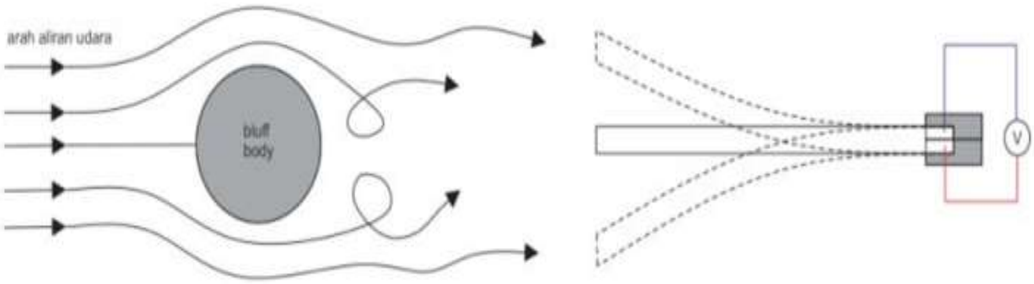

Figure 7. *The concept of a bluff body as a cantilever driving airflow breaker*

3.3. Piezoelectric Speed Bump System Testing

The speed bump system testing is done by testing the mechanical system and the charging capability of the cantilever system. Mechanical system testing is carried out using a reference car to observe the magnitude of the spring deflection. Charging system testing is done by varying the configuration of the piezoelectric and buck converter MB39C811 to obtain the most optimal configuration. The mechanism used in testing the charging system is:

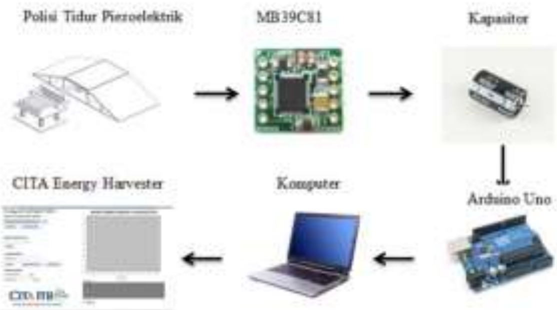

Figure 8*. Testing mechanism for the piezoelectric speed bump charging circuit*

The configurations to be tested include:

1. Piezoelectric single and parallel circuit testing
2. Testing of two parallel piezoelectrics

IV. Results and Discussion

4.1 Results of Discussion Dynamic Performance of the SBEH Simulation

The dynamic performance of the SBEH simulation and vehicles passing through the speed bump was carried out with initial conditions with vehicle speeds of 5 km/hour, 10 km/hour and 15 km/hour.

Table 1. The effect of variations in vehicle speed on the speed bump response

Kec. Mobil (Km/jam)	Kec. Respon SB-F(m/s)	Kec. Respon SB-R(m/s)
5	2,3	2,19
10	1,99	1,87
15	1,54	1,38

The speed bump down speed response to variations in vehicle speed changes is given to a speed bump with the same mass then the speed down as a response generated by the speed bump will be small. Or in other words, the slower the vehicle that crosses the speed bump with the same mass, the lower the speed in response generated by the speed bump will be bigger.

4.2 Cantilever System Test Results

The Kinez K7520BP2 piezoelectric test which is connected in series and parallel proves that the Kinez piezoelectric is only capable of producing an electric voltage when connected in parallel. This is motivated by the basic characteristics of the polarity and polarity of the material found in Kinez K7520BP2[15]. The position of the piezoelectric to the cantilever has an effect on the output voltage. The following are the results of testing the piezoelectric position of the cantilever. Based on the theory, the piezoelectric bending will be greater when it is at the 0 clamp point which causes the piezoelectric output voltage to be greater. The voltage profile obtained after the test shown in Figure 4 is the same as the theory where when the piezoelectric is near the clamp it is able to produce the greatest voltage. Therefore, in the design the piezoelectric position will be placed close to the clamp to obtain the maximum bending.

4.3 Piezoelectric Speed Bump Design Results

The prototype of the piezoelectric speed bump was first designed using SolidWorksTM software by utilizing the configurations that have been tested. The following are the results of the piezoelectric prototype that has been designed.

The prototype of the piezoelectric speed bump consists of a mechanical speed bump system, a cantilever system and an energy harvesting system. The speed bump mechanical system is part of the piezoelectric speed bump which is subject to direct contact with motor vehicle tires. The speed bump mechanical system is designed to withstand an input load of 2707.49 N by utilizing 4 springs that can be passed by one car tire with a spring constant of 75598.24 N/m. The cantilever system is a system consisting of a cantilever system base, retainer, clamp, cantilever plate and piezoelectric material. Cantilever system The cantilever system can accommodate a maximum of 5 cantilever plates. While the energy harvesting system consists of a buck converter MB39C811 and a capacitor which is used to harvest energy as well as storage media.

4.4 Result of Manual Test of Piezoelectric Cantilever System

Testing of the piezoelectric cantilever system is aimed at selecting the most optimal configuration between piezoelectric and buck converters in generating electrical energy. The configuration used is a piezoelectric circuit by utilizing AC1 and AC2 (single piezoelectric circuit) on an MB39C811 and utilizing AC1 (piezoelectric parallel circuit). The test results show that the use of piezoelectric in parallel produces a higher voltage on the 10,000uF capacitor so that in the next design for a piezoelectric system and MB39C811 a parallel circuit is used. After that, identification of the system is carried out by assembling buck converters in series or parallel. The parallel circuit of the buck converter produces a higher voltage because the circuit can collect current continuously even though the input is not continuous, while in the series circuit the buck converter often experiences an open or voltage drop as a result of which the incoming current is not continuous. The next test is to test the effect of adding a piezoelectric system and a buck converter in parallel to the voltage on the capacitor. The test results show that the more piezoelectric used, the greater the energy that can be generated. The relationship between the number of piezoelectrics and the resulting voltage has a linear relationship as shown in Figure 5. The next test is to test the effect of adding a piezoelectric system and a buck converter in parallel to the voltage on the capacitor. The test results show that the more piezoelectric used, the greater the energy that can be generated. The relationship between the number of piezoelectrics and the resulting voltage has a linear relationship as shown in Figure 5. The next test is to test the effect of adding a piezoelectric system and a buck converter in parallel to the voltage on the capacitor. The test results show that the more piezoelectric used, the greater the energy that can be generated. The relationship between the number of piezoelectrics and the resulting voltage has a linear relationship as shown in Figure 5.

Figure 9. *the effect of the number of piezoelectrics on the output voltage*

3.5 Piezoelectric Speed Bump Test Results

Testing the cantilever system with motorized vehicle input using a test car as much as 60 runs on a piezoelectric speed bump. The test can produce electrical energy of 380mV for 1200 seconds with a power of 2,166 mWh. When compared with manual testing with the same conditions, namely 60 beats for 300 seconds, 1120 mV of electrical energy and 75.264mWh of power are obtained. The efficiency of the new piezoelectric speed bump system reaches 2.87%.

Figure 10. *Test results of piezoelectric speed bumps with motor vehicles*

This is due to the mechanical energy transmission of the piezoelectric speed bumps to the piezoelectric cantilever system that has not run optimally. The suboptimal pressure is caused by the speed bump rod not compressing the piezoelectric cantilever system to the maximum due to the vehicle tires that are not always in the center of the speed bump mechanical system. In addition, the mechanical system is not always depressed downward sometimes the pressure causes the knocker to lift up. The unstable speed of the car also affects the speed bump deflection which causes the deflection of the piezoelectric cantilever system to be not always the same in each vehicle's path. The limitations of the test are also in the time it takes the car to run over the speed bump. The average time interval for a car to be able to go back and forth through speed bumps takes 12 seconds. This causes the voltage stored in the capacitor on the MB39C811 to rapidly decrease and tend to run out. This is in contrast to manual testing where the piezoelectric cantilever system is always under pressure at five second intervals.

V. Conclusion

From the results of the design research and simulation of the SBEH speed bump model

1. The resulting maximum descending speed is approximately 2.3 m/s when a vehicle passes the prototype with an average speed of 5 km/hour.
2. The piezoelectric speed bumps that have been designed consist of a speed bump mechanical system, a piezoelectric cantilever system and a buck converter that is capable of producing electrical energy by inputting the pressure of a four-wheeled motorized vehicle. The configuration of the piezoelectric cantilever system that is able to produce optimal voltage is to use several parallel piezoelectric configurations which are connected to the MB39C811 buck converter in parallel. The number of piezoelectric modules and MB39C811 modules has an effect on the amount of energy that can be generated, the more piezoelectric sets and MB39C811 are used, the greater the voltage generated, but there is an optimal value for the number of piezoelectrics used based on mathematical modeling of the system and the size of the speed bumps.
3. the installation of the bluff body causes a vortex in the air flow so as to increase the vibration and electrical voltage in the piezoelectric. The triangular cross-section bluff body has the maximum electrical voltage and the highest average voltage because the flow velocity and the resulting vortex are high

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