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Renewable energy generation using electromechanical speed bump

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ORIGINAL RESEARCH PAPER

ABSTRACT

The design of pollution-free energy recovery systems has become an important goal by researchers as renewable energy is an alternative to traditional energy that depends on fossil fuels. In this work, a multifunctional electromechanical speed bump was invented to be used on the streets to generate clean, sustainable energy by utilizing and investing the kinetic energy of vehicles passing on the roads. The current model was designed to perform three functions simultaneously.

To measure the performance of the innovative speed bump system, a (simplified) prototype was made that simulates the work of the multifunctional bump. The results showed that the proposed initial speed bump model is a promising technology that can be applied as a clean, renewable energy source that can be easily applied in crowded streets.

KEYWORDS

speed bump, renewable energy, clean energy, electromechanical generator

1. INTRODUCTION

Energy is one of the forms of existence, as the universe is made up of bodies and energy. The main types of energy are conventional (non-renewable) energy, including but not limited to oil, natural gas, and coal. It is called non-renewable energy since it needs long periods to substitute. On the other hand, renewable or clean energy comprises wind, solar, hydro-electric, etc. These kinds of energies are inexhaustible. Therefore, the design of renewable energy pollution-free energy systems has become an important research topic by researchers and academia since they tend to be less harmful to the environment [1–3]. The principle of power generation depends on several basic concepts as follows. First, energy transformation transforms energy into forms humans can use and transfer from one place to another. Hence, the electric generator is one of the key elements used to convert a form of energy, such as kinetic energy, into electricity. The hydroelectric dam converts the kinetic energy of water into electrical energy.

The speed bump, the point of interest in this work, can be used as an energy harvester. It is normally employed to regulate the speed of passing cars to ensure pedestrians' safety. However, speed bumps can also generate electricity [4]. In this research, electric power is generated by designing a multifunctional artificial speed bump, which does not lead to any emissions affecting the environment. This can be achieved by investing the weight of vehicles passing on the streets which their use is imperative and repeated daily by members of society to meet their daily needs.

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2. RELATED WORKS

The ideas of generating clean energy are countless and endless, which can be considered the trend of the present era [5]. Applying industrial speed bumps on streets is one way to

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generate clean energy. Yet, the research in this field is somewhat rare and very few. The key related research studies conducted in this regard will be discussed. In [6] the authors used a rack-and-pinion system to generate electricity from an industrial speed bump; they tried to generate power up to 1.9 kW. The authors in [7] designed an energy harvester system from the roadway speed bump. Piezoelectric technology has been used to convert mechanical energy into electrical energy. The resulted power is quite small (4086 mW), which can be used to charge a mobile phone. They used 40 piezo-generators for this purpose. In [8] an energy harvester speed bump system is designed. The approach that has been applied is represented by using a mechanical motion rectifier for converting vertical motions into horizontal rotation. The generated electricity is with the power of up to 200 W.

In [9] a speed bump system is developed to generate electricity using a rack, gears, a belt, and pulleys. The produced power is between 4565 and 5411 W. In this study, a traffic prediction for next years is achieved using an annual dataset for several vehicles. In [10] a speed bump is proposed using the technique of rack and gear along with one-mode clutches. The output power is around 450 W. The authors in [11, 12] have developed a speed bump using a rack and pinion mechanism. The produced power for each study is 4 and 1.2 W, respectively. In [13] a slider-rocker mechanism is designed. The generated electricity is up to 359 W. The authors in [14] proposed a road speed bump using a crank-shaft mechanism. The amount of generated electricity in this study is 1.14 kW. In [15] the authors designed an artificial speed bump to generate electricity. They used an air piston mechanism combined with a rack and pinion system to generate electricity of up to 7.534 kW. The magnetic mechanism is another technique suggested in [16]; the output generated power is 4450 W.

It is worth stating that in most of the prior research work regarding the power generation through the artificial speed bump, it was noted that all previous relevant research had included the design of a traditional single-function speed bump (electrical power generation only) without referring to the investment of this bump in other functions that keep pace with the development of smart cities and Internet of Things (IoT) technology. What distinguishes our current research from previous research is that a multifunctional speed bump has been designed as, in addition to generating electric power, it includes measuring the weights of passing vehicles to measure the weights or overloads that negatively affect the infrastructure of the roads. This also measures road congestion by calculating the average number of passing cars during a certain period.

The main contributions of this work are

1. Designing a system that can generate clean power in crowded streets;
2. Developing multiple functional artificial speed bump systems.

To the best of the author's knowledge, that there is no prior work has used another function for a speed bump, excluding the electricity generation.

3. THE PROPOSED SPEED BUMP

The proposed electromechanical industrial speed bump is designed to transform the vertical linear motion resulting from passing vehicles over the speed bump into a rotational movement that can be doubled and utilized to convert it into electrical energy that can be used, for example, in street lighting at night. The designed bump is a multifunctional interactive bump that can simultaneously provide more than one function. The details of the bump are as follows.

3.1. Components of the proposed speed bump system

When implemented practically in the street, the proposed system consists of the following parts, bearing in mind that the number and size of devices and equipment depend on the amount of energy required to be generated in this system and for each speed bump: high load traffic (crawdad) street; industrial speed bump; Slider Crank; AC generator; charging circuit; energy storage (batteries per speed bump); lighting trigger circuit within a specified time; street light LED; load cell for measurement of vehicle weighing scale; Arduino microcontroller; speed sensors; passive infra-red sensor.

The above are the parts of the real system that can be implemented in a real environment, where for an accurate representation of the input (mechanical energy) and the output (the equivalent electrical energy), mathematical modeling is required for this purpose as it is shown below.

4. MATERIAL MODEL

The weight of the vehicle being applied to the piezo generator is depicted in Fig. 1. When the car drove over the module, z-axis pressure was generated in the active bar, creating a compressive state and positive voltage. When the active bump was returned to its original position by a spring, the piezoelectric material rebounded, which resulted in the generation of a release state and the output of negative voltage.

The load along the z-axis that is being applied to the piezo generator can be stated as follows:

$$M = \frac{P}{2}X, \tag{1}$$

$$M = EI\frac{d^2V}{dX^2}, \tag{2}$$

where P denotes the load being exerted; X is the location of the point on the bump in relation to one of the fixed ends, V is the displacement; E is the modules of elasticity; and I is the moment of inertia. When P is applied, the active bar converts M to X.

The following equations are used to obtain the curvature, dV/dX and a is the distance that separates one fixed end from the beam:

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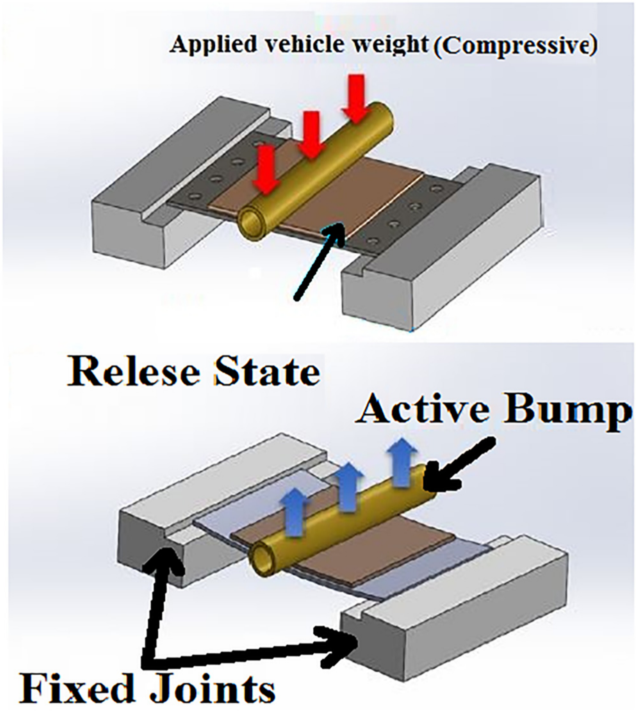

Fig. 1. Piezoelectric generator sketch demonstrates *z*-axis force and vertical displacement in the compression condition and releases state (*Source:* Authors)

$$\frac{dV}{dX} = \frac{P}{4EI}X^2 - \frac{Pa^2}{4EI}, \tag{3}$$

$$V = \frac{P}{12EI}X^3 - \frac{Pa^2}{4EI}X, \tag{4}$$

where a is the distance that separates one fixed end from the beam.

To calculate the displacement at the halfway point X is replaced with a. The displacement V at the point where it is divided by half,

$$V = \frac{Pa^3}{12EI} - \frac{Pa^3}{4EI} = -\frac{Pa^3}{6EI}. \tag{5}$$

Therefore, as the pressure of the vehicle grows, the stress that is applied to the piezo-generator also increases, which results in an improvement in the amount of power that is generated,

$$\text{Mechanical energy } E_m = \int_0^{\Delta t} F \cdot d(t)dt, \tag{6}$$

$$\text{Electrical energy } E_e = p \cdot \Delta t = \frac{K^2}{R} \cdot \Delta t, \tag{7}$$

$$\text{Energy conversion efficiency } (\%) = \frac{E_m}{E_e} \cdot 100, \tag{8}$$

where F is the force result from vehicle weight being applied to the harvester from a push tester; d is the distance that is being moved while the force is being applied; Δt is the amount of time that has been generated; p is the amount of power that is being output by the harvester, Both the amount of voltage that is being output by the harvester and the amount of resistive load that is being applied to the harvester are denoted by the symbols K and R, respectively.

There are two main factors that are tightly correlated to the amount of generated energy in speed bump systems, which are the weight of the vehicles and the frequency of passing vehicles over the speed bump with time. The proposed speed bump is subjected to implement is a crowded street, which already maintained a high frequency of passing cars. Regarding the generated power, a simply prototype to mimic the real speed bump system has been developed. However, as it is mentioned in Eq. (6), the relation between the force and the mechanical energy is a proportional relationship as the force increases the corresponding mechanical energy is increased as well. This is achieved when the amount of force pressure of the vehicle is applied perpendicular to the top surface of the speed bump. On the other hand, as it is mentioned in Eq. (7), a load of vehicles on the harvester can generate electrical energy accordingly. To measure the net efficiency of energy conversion, Eq. (8) is used for this purpose.

5. DESIGNING THE PROTOTYPE OF A SPEED BUMP

For the purpose of studying the possibility of applying the idea of the proposed speed bump system, a simplified prototype was built that simulates the idea of an electromechanical speed bump system with simple and executable devices, and the parts of this prototype as it is shown in Fig. 2.

The device is a mini model that simulates the work of the original speed bump and consists of a simple system for generating electric power through the movement of cars. The system contains a small generator that rotates through pressure on the speed bump. The movement is transmitted to the generator through a mechanical movement of gears, a conveyor belt and a pressure lever, after which it enters a circuit to store and convert the type of current from alternating current to continuous current, and the current is stored in amplitudes for a short time to experiment and communicate the idea of the project. Note that the

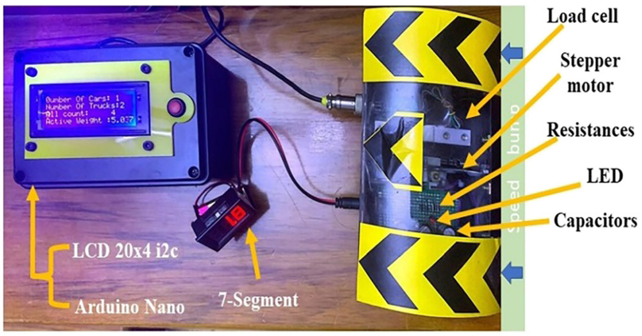

Fig. 2. The proposed prototype of the speed bump (*Source:* Authors)

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expanders take the place of batteries in the practical design when implementation.

The materials used in building the prototype of the speed bump model are divided into two parts: the hardware parts and the software part that receives the data to analyze it to make a decision. First, it is worth stating that the system is designed to generate electricity and measure overweight vehicles and the amount of congestion in the street.

5.1. Hardware components

The speed bump is built from several parts, as follows:

1. Stepper motor;
2. Capacitor type 3200 μF;
3. LED type lamp;
4. Resistance Type 470 Ω;
5. Diode type X4;
6. 7-Segment type digital voltage reader;
7. 20 × 4 i2c type LCD data display;
8. Arduino Nano Microcontroller;
9. Load cell hx711.

5.2. The software part

In this part of the design, an algorithm was built that works on receiving inputs from the system and processing data displayed on the display screen, as it is shown in Fig. 3.

With this addition, the traditional speed bump was converted into an interactive system with multiple functions that could be increased in the future. The detail of the proposed system is demonstrated in Algorithm 1.

Algorithm 1. Multiple functional speed bump system

Input: truck-weight-load, normal load threshold, overload threshold, cars_number_count	
Output: electricity, detect overloaded trucks, measure congestion level.	
1:	If truck-weight-load ≤ normal load threshold
2:	then
3:	cars_number_count+= cars_number_count
4:	Go to: Step 9
5:	ElseIf track-weight-load ≥ overload
6:	Then
7:	Activate emergency alarm (overweight truck)
8:	cars_number_count += cars_number_count
9:	Generate electricity (mechanical to electric power in watt)
10:	Charge batteries
11:	Return (power, cars_number_count,)
12:	EndIf
13:	Go to: Step 1
14:	End

6. EVALUATION AND DISCUSSION

The model simulates the electromechanical speed bump works by pressing the cover or the upper part of the industrial speed bump. The working principle of the proposed prototype is charging the batteries, and here capacitors were used to simulate the batteries that must be charged in the practical device placed on the street. The charging process has been designed to be in both directions, first when pressing the bumper cover towards the bottom and the other when leaving or lifting the load from the bumper cover

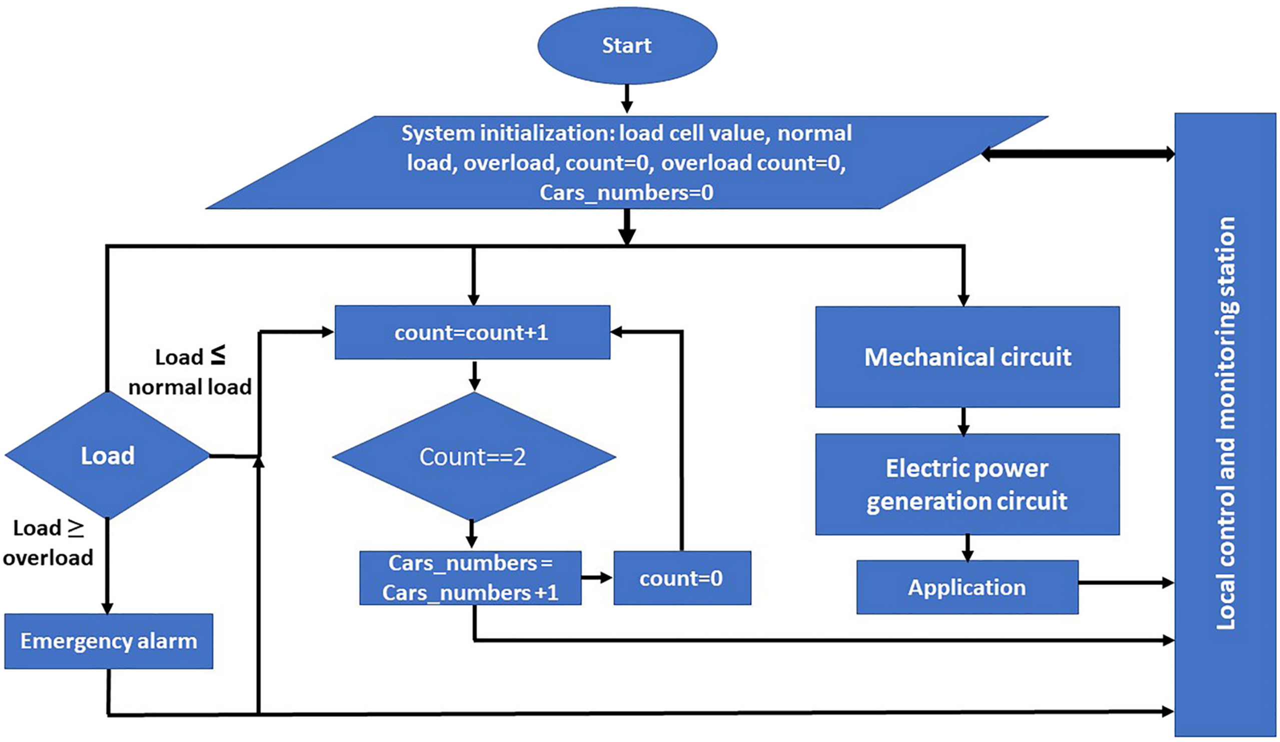

Fig. 3. Flowchart of the proposed speed bump system (*Source:* Authors)

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towards the top. As it is shown in Fig. 2, a LED lamp was used to determine whether the capacitors were charging. At the same time, the 7 Segment digital reader is used to track the voltage in capacitors with each press of the bumper cap. The maximum voltage that can be obtained from the simplified prototype when fully charged is approximately 4 V with power of 500 mW, which is, in fact, a hypothetical voltage for the prototype speed bump simulator only, while in practice and real implementation for the system on actual street, a higher voltage and power can be generated according to the requirements of the application that will be run through this speed bump, using real components such as batteries instead of capacitors. For the part of overweight measurement, the weights that simulated in the prototype are as follows:

- Weight 200–299 g in prototype represents or mimics the small car, which in reality represents the average load weights of 1 t up to 3.5 t;
- Weight 300 g to 399 represents the load vehicle with actual average load weights of 7.5 t–up to 45 t.

The weight greater than 400 g represents the load vehicle with overweight or overload, with average weights load exceeding 50 t up to 60 t.

The crowding measurement by counting the number of vehicles was represented in the simulation model by pressing twice in succession.

7. CONCLUSIONS

An electromechanical speed bump system has been proposed to generate clean, sustainable electric power that can be applied in high-traffic vehicular streets. A simple prototype of the speed bump is developed and tested. It is noted that the desired goal can be achieved, which is to generate electrical power through the use of the electromechanical speed bump.

This system can be used as a substitute for the major national electricity network in natural disasters. The design can reduce the electrical energy consumption through the desired application e.g., turning on street lighting when needed by using a timer for the operation time (when vehicles pass). The proposed design can be used in other applications as an alternative power source when needed. For example, turning on the traffic lights during the day when there is no need for street lighting, which is supposed to work at night.

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