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ROTATIONAL GENERATOR DEVICE IN ROADWAYS

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ABSTRACT:

Economic, environment and social issues in society has led to an interest in the sustainability concept. Sustainable systems have solution for all these concerns. One of the main elements of sustainability in society is transportation's sustainability. The sustainability in transportation systems includes several factors such as safety and energy source. Energy harvesting from roadways has a potential to impact those aforementioned factors. Energy harvesting is capturing unused energy from highways on the purpose of converting it into usable form of energy. In this study, an innovative energy harvesting device has been developed and examined. The device works based on electromagnetic technology. This energy harvesting device captures the kinetic energy from passing vehicles and converts it into electricity depending on a rotational mechanism. Experimental results revealed that the developed prototype is able to generate electrical energy for roadway infrastructures. This generated power could be a reliable source of energy for future roadways, especially in rural remote areas. The device is in its infancy stage of development. Therefore, further development of the prototype is inevitable.

Keywords: *energy harvesting- sustainability- roadway-electromagnetic*

INTRODUCTION

The concept of sustainability attracts a lot of attention due to economic vitality, environmental quality and social equity [1]. Sustainable development is the improvement of quality of life while conserving natural resources [2]. Currently, global developments are causing environmental damages and depleting resources [3]. Sustainable transportation is an essential component of sustainable development [4]. A sustainable transportation system is a safe, affordable, and healthy system, which incorporate renewable resources [5]. However, there are many reasons show that existing transportation networks are not sustainable [6], such as finite fossil fuel reserves serving as a main source of energy; the negative impact on the environment, and excessive fatalities and injuries due to accidents [7].

Significant efforts are being made to attain a more sustainable transportation system [8]. Energy is a central component because energy and related issues play crucial role in the transition towards a sustainable society and transportation system [9]. Thus, renewable energies have received significant attention due to their green and non-polluting nature [10]. Renewable energy improves the ability to maximize transportation-related environmental performance and minimize adverse impacts [11], while also having a major impact on economic growth [12].

Generating renewable energy from the roadway infrastructure, scientifically known as energy harvesting, is an innovative idea on which many researchers around the globe is currently working because it has the potential of solving the energy dilemma and increase the infrastructures' sustainability [13]. In addition , some energy harvesting techniques can help in fixing the energy resource challenge for electrical equipment need in transportation infrastructure—such as wireless sensors—and thereby improve management and safety [14]. Generally, energy harvesting involves converting existing unused environmental energy sources into useful energy that can be utilized for industries [15].

Additionally, energy harvesting can be a reliable source of energy in areas without an energy grid [16]. Signs and lighting fed by energy harvesting sources can notably improve safety in remote areas by mitigating lighting-related accidents [17]. Other applications of energy harvesting technologies in roadways include dissipating heat and controlling pavement distresses [18], mitigating urban heat islands (UHIs) [19], and melting snow in winter seasons [20]. All those applications have positive effects on transportation sustainability. These merits help on promoting the sustainability of transportation systems.

In general, energy harvesting technologies include piezoelectric-based modules [21, 22], asphalt solar collectors [23], thermoelectric systems [24], electromagnetic systems [25], and solar roads [26]. Some of these technologies show acceptable performance in other field such as sensors, accelerometers, micro-motors, and many other low- power applications [27]. Electromagnetic technology is basically based on Faraday's law [28], and electromagnetic energy harvesters convert mechanical energy into electrical power through electromagnetic mechanisms [29]. The general form of Faraday's law, notes that a time-varying magnetic field and spatially electric field always accompany each other [30]. Also recently researcher are developing some intelligent materials like FGPM to find methods and technologies that would be used in this field[31] in this case there are some methods to evaluate this materials in terms of mechanical features [32].

The technology has higher efficiency and power output in applications with larger deflection [33]. Nevertheless, this new technology should not result in an interruption to the transportation system. Therefore, if the electromagnetic harvesters are to be installed in roadways both successfully and effectively, they should be installed in locations where they will cause a minimal traffic flow interruption while being subjected to the maximum possible deflection. One of those ideal locations that can be considered is the location of speed bumps [33]. Thus, the installation of an electromagnetic energy harvester under speed bumps simultaneously contributes to addressing both safety and energy factors in sustainable transportation systems.

There are different mechanisms in electromagnetic energy harvesting technology such as roller-chain system, rack-and-pinion system, cam-arm system, hydraulic power system, and rotational motion [33]. In this study, an innovative electromagnetic device was developed to harvest energy from roadways. Laboratory experimental tests were conducted to evaluate the device's performance in different aspects.

The goal of this study was to develop and evaluate electromagnetic energy harvesting prototype in transportation systems to generate and harvest electric power from passing vehicles. Moreover, the benefits of the technology on sustainability in transportation systems was explored. The specific objectives of the study included the following:

- Developing a prototype.
- Conducting tests to examine the prototype ability in generating power.
- Evaluating the effect of electromagnetic energy harvesting on transportation sustainability.

MATERIALS AND DESIGN

This section presents the mechanism's components and materials used for design and fabrication. Since the study objectives included a preliminary evaluation of the possibility of generating power with these mechanisms, the prototypes were fabricated in small sizes, while the prototype was designed according to two aspects: structure and power generation. The power generation component was designed to capture the wasted energy from a passing vehicle through its speed bump and use it to generate electrical power. The structure was designed to be capable of supporting the entire prototype under heavy loads of passing vehicles. The structure included supports, compression springs, and speed bump. However, the speed bump and compression springs are mutually serving for both power generation and the structural frame. Cylindrical supports were installed to maintain structural integrity and control the speed bump movement. They also play a vital role of protecting other harvester's components from direct contact with the applied loads. Due to large loads in service life and harsh environment conditions, the cylindrical supports were made of steel.

In addition, compression springs were connected to the speed bump and placed inside the supports. Compression springs are crucial elements of the device due to their tasks. Springs help the speed bump move smoothly under the loads, which is important to preserve parts from high stress and to allow drivers to feel less uncomfortable while passing over the bump. They are also responsible of returning the speed bump to its original position, after the load release, and completing the cycle of loading. The springs were made of steel to tolerate frequent wheel loads. Rods connected to the speed bump moved inside holes in the supports to guide the speed bump's movement in a fixed vertical direction.

As mentioned, the speed bump was the only part directly in contact with loads. Thus, the material of the speed bump had to endure the impact of these large loads. In addition, the speed bump was meant to replace the conventional speed bump while capturing wasted energy. Therefore, the designed profile had to be similar to a traditional speed bump. In this laboratory experiment, an aluminum plate with 7.5 mm and heavy duty rubber were used for top plate. 440 mm length was chosen to fit the prototype inside the testing equipment. The width of the speed bump was 300 mm, similar to a conventional speed bump. Figure 1 presents the prototype and its components.

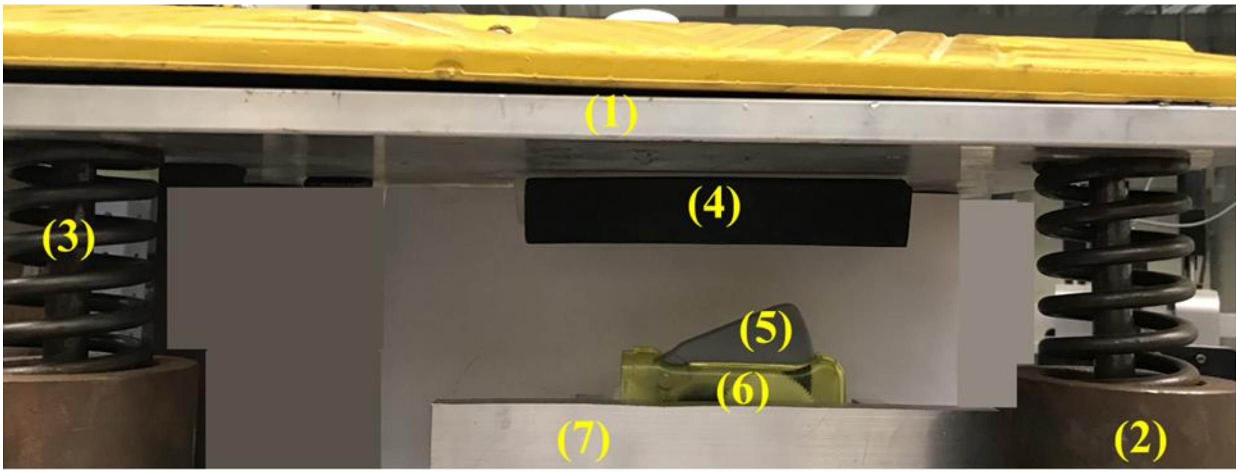

Figure 1. The fabricated mechanism components (1) speed bump; (2) spring support; (3) compression spring; (4) rubber part; (5) lever; (6) Generator includes gears, springs, electrical coil and magnet; and (7) generator support plate.

In the mechanism, the power generation part included a rubber part, lever, generator consists of set of gears, torsion springs, circular magnets, and electrical coil. The rubber part is directly attached to the speed bump and moves downward and upward with it. When the rubber part moves downward, it pushes the lever downward, which is connected to the set of gears. This set of gears receives the vertical movement from the lever and converts it to rotations and conveys it to the permanent magnet. Meanwhile, they also amplify the amount of rotations with the ratio between the gears. The rotation magnets generate a time-varying magnetic field in electrical coil. According to Faraday's law, this time-varying magnetic field produces an electrical power in the electrical coil. When the rubber part moves upward, the torsion springs return the lever to its position. However, due to the study's mechanism design, in this recovering process, it did not generate power, but it is possible to change the design and generate power, even in the recovering process.

EXPERIMENTAL TESTS

The ability of the two mechanisms to generate electrical power was studied in laboratory experiments. A Universal Testing Machine (UTM) was used to simulate traffic loading conditions by applying repetitive loads with different loading frequencies. A Data Acquisition Card (NI DAQ) was used to record the power output. The resistance box was used as an external resistor. Figure 2 illustrates the schematic of the circuit setup for tests.

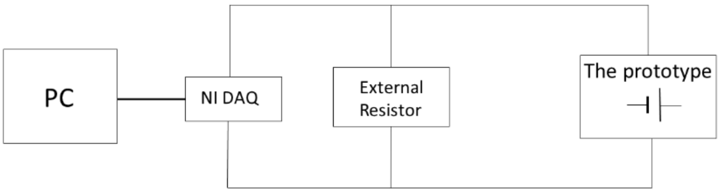

Figure 1. The schematic of the circuit setup

Under real traffic loading the speed bump will experience different loads in its service life due to different vehicle types with different weights, axle configurations, and loading conditions. Thus, to simulate the loads of vehicles' wheels, different loads, 3 and 10 kN, were applied. Loading times and rest periods were chosen to represent a slowing vehicle loading scenario passing over the speed bump. The speed of the vehicle was assumed to be constant. Therefore, three loading-unloading cycles of 0.3, 0.6 and 0.9 second were arbitrarily selected to account for the loading-unloading. The power outputs under different loading conditions were measured.

Table 1 manifests the root mean square of the power outputs of the cantilever and rotational mechanisms in different conditions of loadings. It is clear that increasing the load magnitude has resulted in an increased power output for both mechanisms. This is because increasing the load has increased the relative movements in both mechanisms and thus, the 10 kN loads resulted in the maximum output. However, the effects of the ratio of load magnitudes were different. For instance, the output power decreased by increasing the loading-unloading time. If the load is applied frequently, a smaller time loading means higher frequency, so a higher frequency led to higher output in both mechanisms.

The main cylinder has a mean diameter, D, thickness, t, and hole diameter, D. The ranges of geometry parameters included in this study are shown in table 1.

Table 1.Range of geometrical parameters

Cycle of Loading-Unloading (S-S)	Load (kN)	RMS of Power Output (mW)
0.3-0.3	3	4.8
	10	11.3
0.6-0.6	3	4.1
	10	6.6
0.9-0.9	3	3.5
	10	6.1

It is worth noting that the design and parts used were small in scale since the study was preliminary. In addition, only one set of power generation parts was included in the prototype. It is envisioned that the final design will include multiple parts with a larger size to amplify the power output for each passage. Furthermore, it seems necessary to optimize the design or introduce new or more effective components to maximize power output generation.

In addition, as previously stated, the speed bump shape will be similar in design to the conventional speed bump, which will allow it to control traffic speed and impact safety. Potential locations for prototype installations are any locations with speed bumps, including parking garages, driveway entrances to buildings, school zones, and any other place where the speed of vehicles is to be controlled [34].

BENEFITS TO SUSTAINABILITY STRATEGIES

This section examines the benefits in general of electromagnetic energy harvesting from roadways. Various strategies have been proposed to develop sustainable transportation systems [8]. Intelligent transportation system strategies are promising technology to achieve sustainable transportation system. Intelligent transportation systems include two important section: smart roadways and smart vehicles. Both sections require sensors, communication devices and other kind of facilities to operate. The electromagnetic energy harvesting in roadways can be a considerable source of energy for these necessities.

The proposed electromagnetic energy harvester can supply electrical power for monitoring systems. Advance traffic monitoring systems are crucial for planning the transportation system. These systems record and maintain huge volume of traffic data for planning. Data can be instantly transferred and thus make real-time data possible with infrastructures that are fed with the proposed energy harvester. These real-time data are necessary to manage traffic flow, avoid the accumulation of traffic volume. Moreover, routing/scheduling, removing bottleneck, better accident management are other benefits of the infrastructure provided by the power of energy harvesting technology in roadways.

In general, the electromagnetic energy harvesting prototype will strengthen technological strategies and improve environmental and urban quality of life. It is especially worth noting that the predominant merit of energy harvesting is the capability of providing power for remote areas that lack accessibility to power networks.

CONCLUSION

Electromagnetic energy harvester prototype with rotational mechanism was examined in this study. Laboratory experimental tests were conducted to examine the capability of the prototype to generate power under different loading conditions. The laboratory experimental results showed a promising source of green energy for roadway infrastructures. However, further optimization of the design and utilizing the components at larger sizes is necessary. Furthermore, more studies are required to evaluate the performance of the proposed mechanisms to generate power and endure under real traffic condition.

Moreover, as discussed, using electromagnetic energy harvesting can impact sustainability in transportation. However, this study was only a preliminary evaluation. Thus, further study including quantitative evaluations is needed to consider several other factors.

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