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Proceeding Paper

A Novel Low-Cost Mechanism for Energy Generation through Footsteps †

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Abstract: Energy is the primary concern of the modern era and the requirement of energy is being increased day by day; energy resources are not sufficiently available for sustainable development. It is crucial to generate affordable and pollution-free sources of energy to meet this required demand. Walking is a common daily activity for humans; the kinetic energy from walking is converted into mechanical energy. Moreover, this energy is converted into electrical power using a rack-and-pinion mechanism which is simply a non-conventional method of producing electric current. In this research study, a simple and low-cost rack-and-pinion mechanism with a flywheel is introduced to enhance the performance and efficiency of energy conversion from kinetic energy to mechanical energy and subsequently into electrical energy. The results showed that the proposed footstep floor tile generated an average power of 3 watts for a 0.5 s duration with a peak load of 60 kg. The electrical energy produced per step was noted as 1.8 Joules. A percentage of 75% of the total potential energy theoretically accessible was transmitted by the energy-harvesting paver, and 50% of it was successfully converted into electricity. The generated energy is stored in a backup battery bank system and can be used to charge smart devices, providing a cost-effective and pollution-free solution.

Keywords: power generation; rack and pinion; smart devices; low cost; electrical energy; footsteps; renewable energy

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1. Introduction

The modern era is characterized by an ever-growing need for energy and this demand is being increased extensively with each passing day [1–3]. However, our traditional energy sources are insufficient for power generation and result in an increase in pollutant emissions [4–6]. It is necessary to consider non-conventional energy resources or renewable energy sources that are environmentally friendly [7,8]. Mostf the relevant studies have primarily focused on solar energy, wind energy, and wave energy. However, the operational modes of many of these utilized systems are not sufficiently optimized. This strongly indicates that substantial amounts of energy are still being wasted and could potentially be recovered. With the significant advancement in technologies and our understanding of them, many creative techniques for power generation have developed. These newly developed techniques prioritize based on space limitations and cost-effectiveness [9,10]. Piezoelectric sensors, flywheels and gears, springs, and a rotating generator-powered staircase energy generation system are renewable energy generation methods and are used to generate electricity by implementing Faraday's law of electromagnetic induction [11] but they have complicated designs and are very difficult to apply to a floor tile and cannot generate a significant amount of energy as compared to the design of a rack-and-pinion mechanism [12]. One important and interesting renewable energy generation method is to generate energy through human movement or walking. Walking is a fundamental daily activity for humans: rhythmic motion that produces kinetic energy [13,14]. In order generate energy through a rack-and-pinion mechanism, two steps are involved: the first step involves converting human waste energy into useful mechanical energy, and the second step involves transforming that mechanical energy into electric energy [15].

Alternative energy created from footsteps in a crowded zone is enough for electronic devices. For such devices, it is obvious that a crowded zone can generate power from footsteps. Therefore, the ultimate goal is to develop an affordable smart floor capable of converging kinetic energy from thousands of footsteps into electrical energy. In everyday life, walking is a common part of our routines and in this research study, a cost-effective and efficient method for generating electricity utilizing a rack-and-pinion mechanism was designed and fabricated. To achieve the maximum power output, a consistent maximum average load should be applied to the pinion gears. The kinetic energy generated from the applied load is converted into electrical energy using a rack-and-pinion mechanism. This power generation process utilizes both the upward and downward motion of the rack, which is induced by the applied load, and its upward motion is controlled by springs. The electrical energy is subsequently stored in a power backup battery bank.

2. Design and Fabrication

2.1. Selection of Components

Table 1 represents the specifications of different components of the power generation system.

Table 1. Specifications of different components.

Components	Specifications
Main Frame	Mild steel 1.5 ft × 1.5 ft
Helical Compression Spring	Stainless steel (No. 04)
V-shape Pulleys	02 with ratio 4:1
Pillow block Bearing	Chromium steel Internal Dia = 25 mm External Dia = 35 mm
Rack	Length of Rack = 0.2 m Number of Teeth = 28
Flywheel	Dia of Flywheel = 75 mm
Generator	150–200 RPM, 12 V, 20–30 Watt

2.2. Design of Spring

Four helical compression springs were employed for the design of the power generation system. The spring's characteristics are listed below. The spring was designed according to the formula shown in Equation (1).

$$D = \sqrt[3]{\frac{Gd^4}{8nk}} \quad (1)$$

where D is the outer diameter, G is the modulus of rigidity, d is the inner diameter, n is the number of coils, and k is the stiffness; the spring was designed by taking values of 574 N/m and 0.03 m for the stiffness and outer diameter, respectively.

2.3. Design of Rack and Pinion

The system was designed to produce maximum power with an average load of 60 kg on the tail floor. The gear was designed using the formula given in Equation (2), where the number of teeth was set at 27, the angle was 20°, the circular pitch was 15 mm, the pitch diameter was 50 mm, the addendum and dedendum were 4.77 mm and 5.52 mm, respectively, and finally, the tooth thickness of the gear had a value of 5.82 mm.

$$Tooth\ Thickness = \frac{\pi \times Pitch\ diameter}{N} \quad (2)$$

Finally, the gear (pinion), flywheel, and generator were installed on the main shaft with a belt and pully. The different components and final assembly of the power generation system are shown in Figures 1 and 2, respectively.

Figure 1. Different components of power generation system.

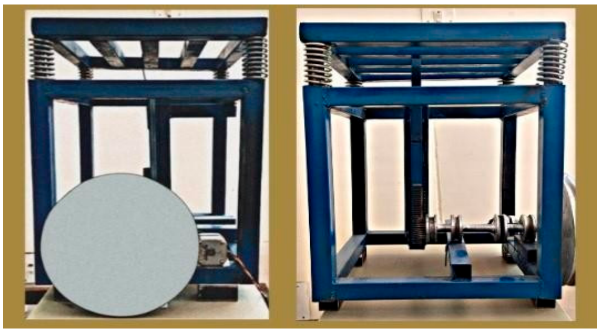

Figure 2. Final assembly of power generation system.

2.4. Principle of Working

Electricity was generated from a speed breaker using a rack-and-pinion arrangement. This approach can generate a substantial amount of electricity. The rack–pinion mechanism is a simple and efficient design for generating a good amount of energy using an electrical generator. The block diagram of electricity generation using rack-and-pinion power generation systems is given in Figure 3.

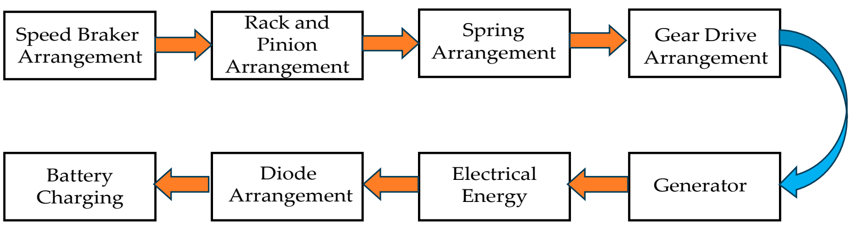

Figure 3. Block diagram of electrical energy generation.

When a load is applied to the footstep power generation system, the plates move downward as force is exerted on the tiles, causing the springs to compress. Subsequently, the rack also moves in a downward direction. As the rack moves, the pinion engages with the rack gear and initiates a circular motion of the pinion gear. Pitch travels a half-circle at every complete compression. Once the force on the plate is removed, the pinion reverses, completing another half-circle. The sinusoidal waveform is the result of the dynamo coupled to the shaft and pinion. A flywheel is employed to ensure smooth and consistent motion. The DC generator produces direct current (DC) power, which is stored in a battery. This generated power can be utilized for domestic or commercial purposes, particularly those in close proximity to a speed breaker.

3. Results and Discussion

This model illustrates how densely populated areas can generate electrical power. The load range for the footstep power generation system starts from 40 kg to 80 kg, and the measured parameters include power generated, voltage, current, and flywheel energy. Table 2 represents the experimental results for power generation, current, voltage, and energy stored in the flywheel due to the applied load.

Table 2. Experimental results of power generated, current, volage, and energy stored in flywheel due to applied load.

Sr No.	Applied Load (kg)	Power Generated (Watt)	RPM (N)	Energy Stored in Flywheel (Joule)
1	45	12	120	53
2	60	28	265	257
3	70	43	416	634
4	80	56	541	1072

The purpose of this research was to investigate power generation, and a linear relationship was observed between the power generated and the applied load during experimental testing of the power generation system. The maximum average power generation reached 56 watts when an 80 kg load was applied, as shown in Figure 4 and in accordance with previous research [12–15]. Also, a linear relationship was observed between RPM and energy stored by the flywheel, with a maximum of 1072 joules of energy stored at 541 RPM of the flywheel. Energy is stored in the flywheel by accelerating a rotor to a very high speed and maintaining the energy in the system as rotational energy. The energy is pulled out from the system, but the shaft continues to rotate due to the rotational energy stored in the flywheel, which maintains the system in rotational movement for some time until the rotational energy that was stored is completely utilized. The linear relationship between energy stored and RPM is shown in Figure 5.

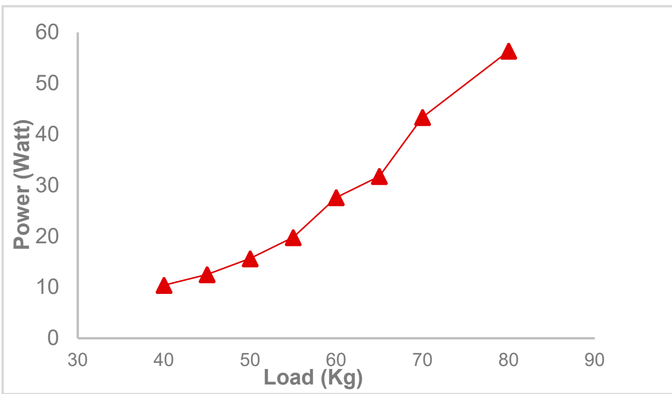

Figure 4. Relationship between applied load and power generated from the system.

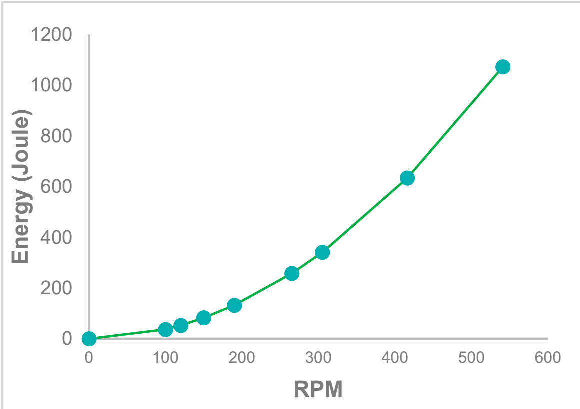

Figure 5. Relationship between RPM and energy stored in flywheel.

Voltmeters were used to measure voltages. When RPM increases, voltage and current also increase; the maximum average values of voltage and current were recorded as 7.90 V and 1.90 Amp, respectively, when 541 rpm was provided to the system. A linear correlation between current and voltage is shown in Figure 6.

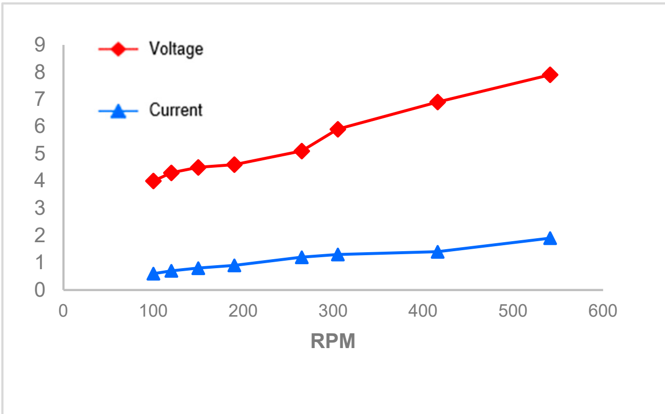

Figure 6. Relationship between voltage and current generated with respect to RPM.

4. Conclusions

An alternative mechanical-based power generation method using a rack-and-pinion mechanism was proposed and human footsteps were used for power generation. In this experimental study, a low-cost model was designed and developed for power generation through mechanical methods using a rack and pinion and experimental results were analyzed, and we found a direct relationship between power generation and applied load. The second object was a low cost that was also achieved during this experimental study and it was also noticed that this method is environmentally friendly as it does not require fuel. An average value of 56 watt was achieved with an 80kg applied load. A percentage of 75% of the total potential energy theoretically accessible was transmitted by the energy-harvesting paver. This footfall power generation system is a viable solution for energy crises and offers a cost-effective alternative to other energy generation methods.

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References

1. Khan, A.N.; Begum, T.; Sher, M. Energy crisis in Pakistan: Causes and consequences. *Abasyn J. Soc. Sci.* **2012**, *2*, 4.
2. Nikleshwar, E.; Sindhuja, D.; Charan, T.S.; Basha, R.M. Heart disease prediction using machine learning. *Int. J. Appl. Sci. Eng.* **2023**, *11*, 946–950. [CrossRef]
3. Sailaja, M.; Raja Roy, M.; Kumar, S.P. Design of rack and pinion mechanism for power generation at speed breakers. *Int. J. Eng. Technol.* **2015**, *22*, 356–362.
4. Rajarathinam, M.; Ali, S.F. Energy generation in a hybrid harvester under harmonic excitation. *Energy Convers. Manag.* **2018**, *155*, 10–19. [CrossRef]
5. Ascanio-Villabona, J.G.; Sandoval-Rodriguez, C.L.; Rincón-Quintero, A.D.; Tarazona-Romero, B.E.; Paez-Castro, R.E. Building a prototype for functional analysis of the energy potential of the water flow in pipe 1/2 "using microturbines applied to Unidades Tecnológicas de Santander. *IOP Conf. Ser. Mater. Sci. Eng.* **2020**, *844*, 012056. [CrossRef]
6. Tan, Y.K.; Panda, S.K. Energy harvesting from hybrid indoor ambient light and thermal energy sources for enhanced performance of wireless sensor nodes. *IEEE Trans. Ind. Electron.* **2011**, *58*, 4424–4435. [CrossRef]
7. Rafique, S. Overview of vibration energy harvesting. In *Piezoelectric Vibration Energy Harvesting*; Springer International Publishing: Cham, Switzerland, 2017; pp. 9–30. [CrossRef]
8. Panwar, N.L.; Kaushik, S.C.; Kothari, S. Role of renewable energy sources in Environmental Protection: A Review. *Renew. Sustain. Energy Rev.* **2011**, *15*, 1513–1524. [CrossRef]
9. Andriopoulou, S. A Review on Energy Harvesting from Roads. Master's Thesis, KTH, Stockholm, Sweden, 2012.
10. Batra, A.K. Simulation of energy harvesting from roads via pyroelectricity. *J. Photonics Energy* **2011**, *1*, 014001. [CrossRef]
11. Lowattanamart, W.; Suttisung, V.; Sintragoonchai, S.; Phanomchoeng, G.; Jintanawan, T. Feasibility on development of Kinetic-energy harvesting floors. *IOP Conf. Ser. Environ. Earth Sci.* **2020**, *463*, 012107. [CrossRef]
12. Hossain, M.E.; Hasan, M.R.; Ahmed, K.T.; Shawon, M.N. Design and performance of power generation using speed breaker with the help of rack and pinion mechanism. In Proceedings of the 2017 4th International Conference on Advances in Electrical Engineering (ICAEE) 2017, Dhaka, Bangladesh, 28–30 September 2017.
13. Gordon, D.; Robertson, E.; Winter, D.A. Mechanical energy generation, absorption and transfer amongst segments during walking. *J. Biomech.* **1980**, *13*, 845–854. [CrossRef] [PubMed]
14. Ahamed, M.A.; Reza, M.I.; Al-Amin, M. Electricity generation from speed breaker by air compression method using Wells Turbine. *Int. J. Adv. Eng. Comput. Technol.* **2020**, *4*, 140. [CrossRef]
15. Asad Saeed, M.; Hamza Tahir, M.; Zaffar, N.; Malik, A. Design of footstep power generation system using rack and pinion gears mechanism. *Int. J. Eng. Technol. Appl. Sci.* **2019**, *4*, 48–52.