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Dynamic Roadway Energy Harvesting and Power System

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Abstract
This paper presents a sustainable method for generating electrical energy from vehicular motion using a spring-based speed breaker. The proposed system harnesses kinetic energy, converting it to electricity through mechanical compression and generation. A prototype demonstrates the feasibility of powering streetlights and low-energy applications. Comprehensive analysis including design, fabrication, testing, advantages, and scalability are discussed.

Keywords: Energy harvesting, Speed breaker, Mechanical energy conversion, Renewable energy, Smart city infrastructure

1. Introduction

The need for renewable energy solutions is more urgent than ever due to the increasing demand and depletion of conventional resources. Speed breakers are commonly used to regulate speed and enhance safety on roads, but they also present an opportunity to harvest energy from vehicular motion. When vehicles pass over a speed breaker, kinetic energy is normally dissipated as heat and vibration. This system aims to capture that energy using a spring-based design, converting mechanical compression into electrical energy.

This project explores a practical approach to capturing energy from traffic through a robust mechanical system that includes springs, a generator, and energy storage devices. By employing a smart, simple design, it demonstrates how everyday infrastructure can be transformed into a renewable energy source, providing supplemental power for streetlights, traffic signals, or charging stations.

2. Literature Review

Gupta et al. implemented vehicle-powered generators to illuminate roadside villages. Zabihi and Saafi (2023) reviewed smart road infrastructure energy systems, emphasizing sustainability and integration with urban planning. Kharche et al. designed a rack and pinion system yielding 273W from a 400kg vehicle.

Iqbal et al. used chains and flywheels in spring systems to generate DC power. Rao et al. utilized crankshafts and springs to optimize conversion. Pitre et al. reported an instantaneous 2000W using lever systems with cars at low speed. Despite innovation, these studies lack real-world deployment, cost analysis, and scalable implementation.

Abhishek Gupta et. alThe energy crisis inspired the idea of generating power using speed breakers, initially implemented in South Africa to light small villages along highways. By converting the kinetic energy from vehicles passing over speed breakers into electrical energy, this concept has since evolved. Motivated by this idea, our team has decided to develop a project that generates more power and stores it for nighttime use, aiming to benefit the country's economy[1].

Zabihi, N., & Saafi, M.

The paper "Recent Developments in Energy Harvesting from Road Infrastructures" explores technologies for harvesting energy from roadways, including speed breakers. It reviews mechanisms like piezoelectric and electromagnetic systems, focusing on their efficiency, applications, and sustainability benefits, while highlighting innovative designs and the integration of smart energy solutions in urban areas. (2023).

Laukik Kharche, Kalpesh Jadhav, Pranay Gawas, Chaitali Gharat.

The Speed Breaker Power Generator (SBPG) uses a rack and pinion mechanism to convert vehicle motion into electricity. When a car passes, the rack moves, generating rotary motion to power a DC generator and store energy in batteries. The system can generate 273.24W with a 400kg vehicle, producing 54.59 kWh in an hour from 100 cars, utilizing both downward and upward motion.(2022)

MD. Iqbal Hossain,Rupa Akter,Mahedi Hasan, Ahamed Raihan,M. F. Shahriar Khan

This electro-mechanical electric generator uses a sprocket, chain, gear, flywheel, bearing, spring, generator, and battery to produce electricity from road transport pressure. When pressure is applied to the lever, it rotates the wheels, generating electricity in a DC generator. The power produced can meet local demand and potentially help address national energy shortages.(2021)

D.Venkata Rao , K.Prasada Rao , S.Chiranjeeva Rao and R.Umamaheswara Rao

The depletion of fossil fuels and their environmental impact drive the need for renewable energy. Road power generation, using vehicle weight and motion, offers a sustainable solution. Speed breaker systems convert mechanical energy into electricity with components like levers, springs, and crankshafts. Tools like Pro-E optimize system efficiency. Practical applications include powering streetlights and traffic signals in high-traffic areas. Comparisons of theoretical and practical outputs demonstrate the feasibility of this technology in reducing fossil fuel dependence and promoting sustainability.(2018)

Mrs. S.S Pitre , Mr. Rahul Raj , Mr. Sachin Raina , Mr. Akash Bhoria , Mr. Alok Kumar

Observes customers pull in and out all day, and at least 100,000 cars visit the drive-thru each year. and a newly installed, mechanized speed bump(video) will both help them slow down and harvest some of that coasting energy. The weight of a car is used to throw a lever, explains Gerard Lynch, the engineer behind the Motion Power system developed for New Energy Technologies, a Maryland-based company. "The instantaneous power is 2,000 watts at five miles-per-hour, but it's instantaneous which means some form of storage will be required. (2018)

3. Literature Gap

While innovation in roadway energy harvesting exists, most studies have not addressed:

- Real-world scalability across traffic densities
- Energy storage and long-term reliability
- Integration with smart city platforms
- Lifecycle cost and environmental analysis

While various mechanisms, such as spring-based systems, piezoelectric systems, rack-and-pinion mechanisms, and lever-based mechanisms, have been explored ([3], [4], [6]), no detailed study compares the efficiency, durability, and scalability of these systems under different traffic and environmental conditions. The absence of a holistic comparison leaves questions regarding the optimal mechanism for specific use cases

Many studies ([1], [3], [6]) briefly mention the need for energy storage but fail to delve into detailed analyses of storage technologies, such as batteries or supercapacitors, and their long-term performance in these systems. Efficient and sustainable energy storage is critical for making these systems viable, particularly for nighttime use or areas with intermittent traffic.

Most studies focus on theoretical frameworks or controlled experimental setups ([4], [5]), with minimal analysis of large-scale deployment in real-world environments. Factors such as traffic diversity, varying vehicle weights, environmental conditions, and long-term maintenance costs are underexplored.

Although some papers highlight cost-related aspects ([1], [5]), a comprehensive cost-benefit analysis, including installation, operational, and maintenance costs, along with return on investment (ROI) for large-scale projects, is missing. The economic feasibility of deploying such systems on urban or national scales remains unclear.

While [2] emphasizes the integration of smart energy solutions, other studies lack focus on how speed breaker power generation can be seamlessly integrated into existing smart city infrastructure, such as IoT-enabled grids or adaptive energy systems. This represents a gap in aligning energy harvesting with modern urban development goals.

Limited research ([1], [5]) addresses the broader environmental impact of deploying such systems, including material sustainability, manufacturing processes, and the lifecycle carbon footprint. A comprehensive environmental assessment is necessary to validate their status as "green energy" solutions.

While several studies ([3], [5], [6]) report power output and theoretical efficiency, little research focuses on optimizing the design of speed breaker systems to maximize energy conversion rates under real-world conditions, such as varied traffic volumes, vehicle speeds, and axle loads.

Although [1] and [4] suggest potential applications in rural and urban areas, they do not address scalability challenges, such as adapting designs to high-density urban areas with different traffic patterns compared to rural highways with sporadic traffic.

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4. Objectives

- Design an efficient energy conversion system based on vehicle-induced compression
- Fabricate and test a prototype with a DC generator
- Store and utilize generated energy for streetlight-level power
- Analyze practical deployment challenges and scalability

5. Methodology

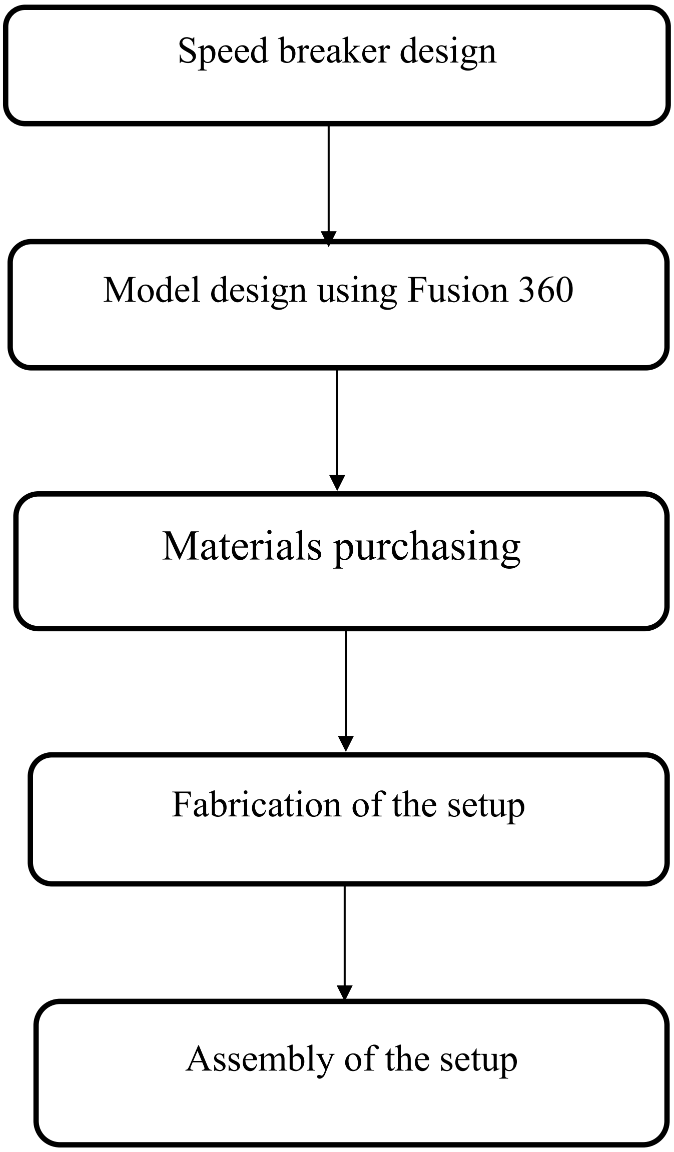
The methodology included component selection, CAD design (Fusion 360), material procurement, fabrication, and testing. Key stages:

- Designing a spring-based speed breaker
- Mechanical energy transfer to DC generator
- Energy regulation and storage in batteries

- Performance testing using simulated vehicle weights

6. Flowchart

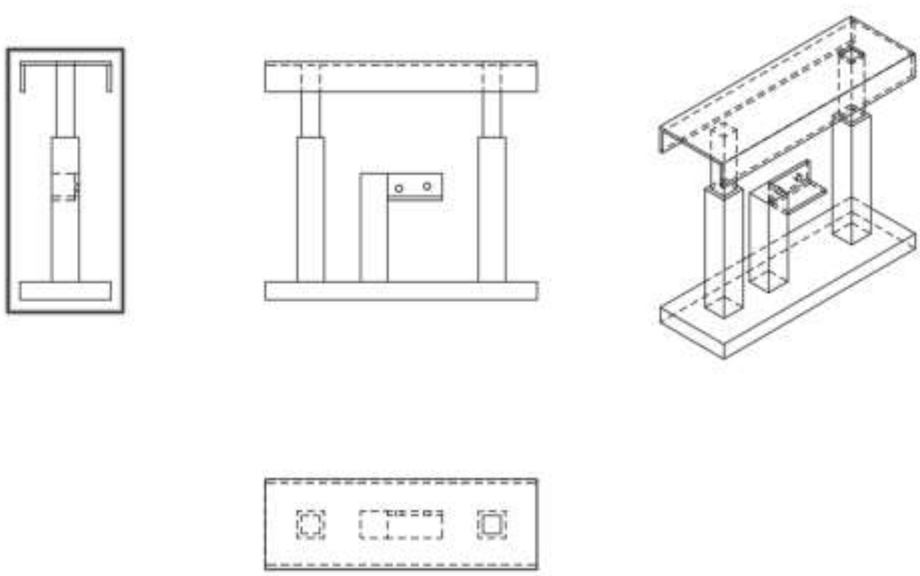
The following flowchart outlines the project methodology:



7. Design and Fabrication

Fusion 360 was used to model the system in 2D and 3D. Mild steel was chosen for the frame due to its durability. Components included springs, a DC generator, support brackets, and linkages. Fabrication involved cutting, drilling, welding, and assembling components into a working prototype.

Photographs documenting each stage of the build process are included below.



(Fig 1)2-D Model made using Fusion 360

(Fig 2) 3-D Model made using Fusion 360

(Fig 3)Cutting of the framework

(Fig 4)Welding of the frame work

(Fig 5)Frame work after welding

8. Results

The prototype successfully powered three LED bulbs from three spring compressions. Energy conversion was effective and consistent. The results indicate high potential for small-scale energy needs and proof-of-concept for larger systems.

9. Advantages and Limitations

Advantages

- Eco-friendly and sustainable
- Reduces grid dependency
- Uses existing road infrastructure
- Suitable for both rural and urban areas

Limitations:

- Low energy yield in low-traffic areas
- Requires robust maintenance
- Needs better energy storage
- Design optimization needed for large vehicles

10. Scope for Future Work

To enhance impact and scalability, future research should focus on:

- Smart grid integration
- IoT-based monitoring
- Advanced batteries
- Urban traffic modeling
- Materials research for spring fatigue
- Cost optimization
- Public-private partnerships for real deployment

11. Conclusion

The spring-based energy harvesting speed breaker demonstrates a simple, reliable, and green way to generate electricity in areas with moderate to high traffic. Its small-scale application can be extended to contribute to smart city energy planning. Continued development could lead to widespread adoption as a supplemental power solution.

1. The project demonstrated the feasibility of using spring-based speed breakers to generate electrical energy.
2. The system efficiently converted mechanical energy from vehicles into electricity with minimal energy loss.
3. It successfully powered three LED bulbs, proving its potential for small-scale energy applications.
4. This technology can be scaled to power streetlights, traffic signals, and public infrastructure in high-traffic areas.

12. References

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