Smart Speed Breaker for Energy Harvesting Applications

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Abstract. This study presents the design, analysis, and preliminary evaluation of a screw-jack–based smart speed breaker intended to harvest electrical energy from vehicle motion. The system converts vertical displacement caused by vehicular loading into rotational motion via a mechanical screw-jack assembly, which subsequently powers a generator. A detailed review of speed breaker mechanisms, energy harvesting methods, and screw-jack transmission principles provides the theoretical foundation. The project includes system modelling, selection of mechanical and electrical components, prototype fabrication, and testing under controlled loading scenarios. Experimental results revealed structural limitations in the screw-jack mechanism, prompting a redesign proposal using a rack-and-pinion configuration to improve reliability and output. The study highlights the potential of road-integrated mechanical energy harvesting for powering low-consumption devices in smart transportation environments.

Keywords: Speed breaker generator, Screw jack mechanism, Energy harvesting, Mechanical-electrical conversion, Smart Road systems, Rack-and-pinion.

1 Introduction

The increasing global demand for energy, coupled with the need for sustainable and cost-effective alternatives, has driven interest in mechanical energy harvesting technologies. Road traffic represents a largely untapped energy source, particularly in regions with high vehicle density. Smart speed breakers have emerged as a viable means of extracting energy from vehicular motion by converting vertical displacement into mechanical work [1]. This concept aligns with emerging smart-city frameworks, where distributed micro-generation systems support decentralized electrical loads such as streetlights, signage, and pedestrian infrastructure.

In Oman, expanding road networks and consistently high vehicle usage offer significant potential for implementing road-based energy harvesting systems. A geographic overview of the national road network is shown in Figure 1.

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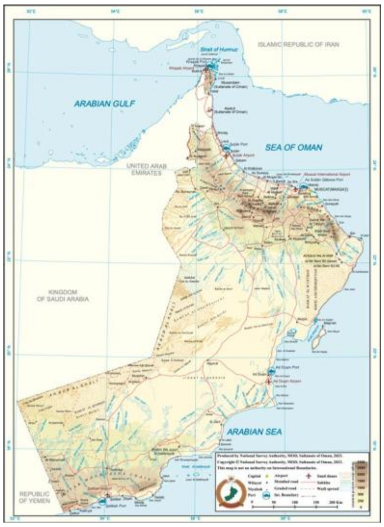

Fig. 1. Road network map of Oman.

Traditional speed breakers were primarily introduced for traffic speed control, but over time, researchers have explored their functionality as energy sources. Early mechanical designs involved simple deflection-based mechanisms shown in Figure 2, while modern systems integrate electromechanical conversion components to increase efficiency.

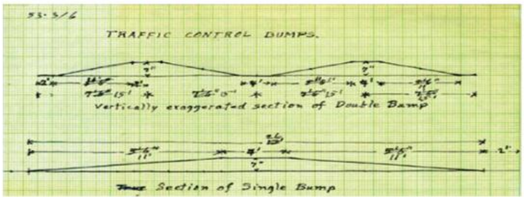

Fig. 2. Historical development of early speed bump mechanisms.

However, conventional speed breakers may present disadvantages such as structural wear, user discomfort, and reduced efficiency when improperly designed shown in Figure 3. This project aims to address these gaps by evaluating a screw-jack–based conversion system for harvesting energy from vehicle-induced loads. The study focuses on mechanical performance, load response, system feasibility, and potential improvements to enhance energy conversion capacity.

Fig. 3. Example disadvantages of conventional speed bumps.

2 Literature Review

2.1 Overview of Speed Breaker Energy Harvesting Systems

Energy harvesting from speed breakers typically involves converting the downward force and displacement from vehicle movement into electrical energy. Various mechanisms have been explored, including:

- **Compression-spring systems**
- **Hydraulic dampers**
- **Rack-and-pinion assemblies**
- **Piezoelectric tiles**
- **Flywheel-based mechanisms**

Mechanical systems remain attractive due to their low cost, simplicity, and ability to withstand high loads [2].

2.2 Screw Jack Mechanism for Mechanical-Electrical Conversion

A screw jack converts linear motion into rotational motion using a threaded shaft and nut assembly. When a load is applied vertically, the screw rotates, producing torque suitable for driving a generator. This principle makes screw jacks promising candidates for energy harvesting applications due to:

- High load-bearing capacity
- Simple mechanical construction
- Large mechanical advantage

The concept applied in this project is illustrated in Figure 4.

Fig. 4. Mechanical concept of screw-jack-based energy harvesting.

However, screw jacks also have drawbacks, including friction losses, wear under cyclic loading, and the need for precise alignment to avoid thread failure [3].

2.3 Electromechanical System Components

Energy harvesting systems typically include:

- A **mechanical input unit** (speed breaker mechanism)
- A **motion conversion system** (screw jack or rack-and-pinion)
- An **electrical generator or DC motor**
- A **power conditioning unit** (capacitors, rectifiers, or BMS)
- **Energy storage** (battery or supercapacitor)

Figures 5–8 provide an overview of the key components used in this project.

Fig. 5. Screw jack prototype with motor coupling.

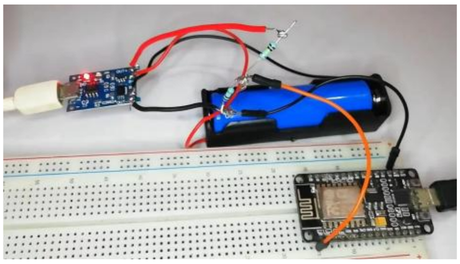

Fig. 6. Battery with BMS testing arrangement.

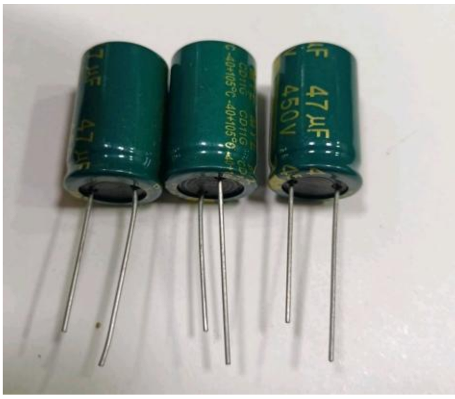

Fig. 7. Capacitor bank used for voltage stabilization.

Fig. 8. Arduino-based subsystem for measurement and control.

These components together support effective conversion, regulation, and utilization of the harvested energy [4].

2.4 Smart Road Infrastructure Applications

Smart transportation systems increasingly integrate micro-generation components for powering:

- Lane lighting
- Traffic monitoring sensors
- Warning signals
- IoT-based road safety devices

Speed-breaker-based harvesters represent a decentralized and maintenance-friendly solution for such applications, especially in regions with high vehicle frequency [5].

2.5 Identified Research Gaps

Key research gaps derived from the literature include:

- Limited analysis of screw-jack durability under repeated vehicular loading
- Insufficient evaluation of real-world load distribution across speed breakers
- Need for improved mechanical designs to minimize failure during high-impact events
- Lack of integrated testing combining mechanical, electrical, and storage subsystems

This project contributes by experimentally evaluating failure points and proposing an improved energy harvesting mechanism.

3 Methodology

The methodology for developing the screw-jack–based energy harvesting speed breaker consisted of four stages: (1) conceptual design, (2) mechanical and electrical component integration, (3) prototype testing, and (4) analysis of failure points to propose an improved system.

3.1 Conceptual System Design

The system was designed to convert the downward displacement caused by a vehicle traversing the speed breaker into rotational motion using a screw-jack assembly. The project adopted a linear-to-rotary conversion approach in which:

- The speed breaker plate transfers load vertically
- The screw jack translates vertical motion into rotational torque
- A DC motor acts as a generator to produce electrical output

The overall functional workflow is presented in Figure 9.

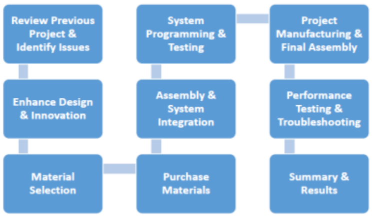

Fig. 9. System workflow diagram for screw-jack energy harvesting.

3.2 Mechanical Subsystem

The mechanical subsystem consists of:

- A **load-bearing platform** acting as the speed breaker
- A **screw jack mechanism** mounted vertically beneath the platform
- A **support frame** designed to withstand vehicle loads
- A **coupling shaft** linking the screw rotation to the generator

The screw jack used is shown in Figure 5 (referenced earlier), with specifications selected to balance load capacity and mechanical advantage.

Key design considerations:

- Thread pitch to control torque output
- Structural rigidity of the base frame
- Compression distance under vehicular load
- Resistance to repeated cyclic loading

3.3 Electrical Subsystem

The electrical system included:

- A **DC motor** functioning as a generator
- A **capacitor bank** for smoothing output voltage (Figure 7)
- A **Battery Management System (BMS)** for controlled charging (Figure 6)
- An **Arduino unit** for voltage monitoring (Figure 8)

Each electrical component was tested individually before being integrated into the system.

3.4 Prototype Testing Setup

Testing was conducted in a controlled environment using:

- Vertical manual loading to simulate vehicle force
- Measurement of torque and rotational angle
- Voltage output readings from the generator
- Observation of mechanical deformation, thread stability, and motion transfer efficiency

The prototype was not tested under actual vehicle loads due to safety limitations; instead, the system was subjected to scaled-down manual compression to identify mechanical weaknesses.

4 Results and Discussion

4.1 Mechanical Performance and Failure Analysis

Initial testing revealed that the screw jack experienced mechanical failure under repeated loading. The threads deformed, and the lifting mechanism jammed, preventing consistent rotation.

The failure observed is shown in Figure 10.

Fig. 10. Screw jack mechanical failure during testing.

Key causes identified:

- Excessive compressive force exceeding screw material limits
- Misalignment between the moving plate and screw axis
- High friction at thread interfaces
- Lack of load distribution across the speed breaker surface

These findings align with literature indicating that screw jacks are not ideal for dynamic, high-impact loads [6].

4.2 Electrical Output Evaluation

Due to mechanical failure, continuous rotation of the screw jack could not be maintained; however, during brief rotations, the generator produced measurable voltage spikes.

Observations:

- Voltage output was inconsistent
- Capacitors effectively smoothed transient peaks
- BMS responded correctly to input variations

Although full system evaluation was not possible, electrical subsystem functionality was validated.

4.3 Proposed New Mechanism: Rack-and-Pinion System

To address the mechanical limitations of the screw jack, the team proposed replacing it with a **rack-and-pinion** mechanism, which offers:

- Improved load distribution
- Reduced friction losses
- Greater structural reliability
- Simplified motion transfer to rotational output

The conceptual redesign is shown in Figures 11 and 12.

Fig. 11. Proposed spring-supported rack-and-pinion mechanism.

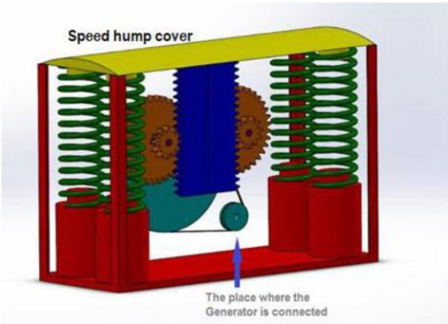

Fig. 12. Conceptual redesign scheme for improved energy harvesting.

This redesign enables smoother rotational motion, better durability, and more predictable energy output under vehicular loads.

4.4 System Feasibility Assessment

Strengths of the proposed system:

- Mechanical simplicity
- Low-cost materials
- Suitable for high-traffic areas
- Strong potential for powering low-energy devices such as LEDs, sensors, or road beacons

Limitations identified:

- Output highly dependent on vehicle frequency
- Requires robust structural design to withstand long-term loading
- Electrical output remains modest and not suitable for high-power applications

Overall, the project demonstrates feasibility but requires mechanical redesign for deployment in real road environments.

5 Conclusion

This study explored the feasibility of harvesting energy from vehicle-induced pressure using a screw-jack–based smart speed breaker. The system was designed, fabricated, and evaluated through mechanical and electrical subsystem testing. Initial results demonstrated that the screw-jack mechanism failed under repeated loads, preventing reliable energy generation.

Despite this, the project successfully validated the energy harvesting concept and identified the limitations of screw-jack mechanisms for dynamic road applications.

An improved rack-and-pinion concept was proposed, offering better load transfer, reduced friction, and enhanced structural stability.

This research contributes to ongoing efforts in micro-energy harvesting within smart transportation systems and highlights the importance of mechanical durability in real-world deployment.

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