Electricity Generation From Speed Breakers Using Rack-And-Pinion Mechanism With DC Generator

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Abstract- *Energy scarcity and depletion of non-renewable fossil fuels are two of the most pressing challenges facing modern civilization. This paper proposes and analyses a novel, low-cost mechanism for harvesting electrical energy from the kinetic energy dissipated by vehicles crossing road speed breakers. The proposed system — the Power Hump — integrates a rack-and-pinion mechanism beneath a spring-loaded speed breaker plate. Vehicular pressure drives the rack downward, rotating a pinion gear. Through a compound gear train (1:5 speed ratio) and belt drive, rotational motion is transmitted to a DC generator capable of generating up to 70 V. Electricity is stored in a 12 V rechargeable battery for road and street lighting. A CATIA V5 three-dimensional CAD model has been developed to validate the mechanical design. Experimental results demonstrate stable voltage and current output across varying vehicle loads. A single Power Hump unit can generate approximately 3.5 kWh per day at a moderately busy intersection, sufficient to power 8–10 LED street lamps throughout the night.*

Keywords: Speed breaker, kinetic energy harvesting, DC generator, rack-and-pinion, Power Hump, renewable energy, road lighting, CATIA V5.

I. INTRODUCTION

In the present scenario, power has become a critical need for all aspects of human life. India — with 20% of world population — accounts for only 1% of global energy consumption, with a per-capita electricity consumption of roughly 150 kWh versus 8,000 kWh in the USA [1]. Conventional fossil fuels are rapidly depleting, while pollution from power stations and automobiles continues to harm ecosystems globally.

The Power Hump concept captures the kinetic energy dissipated by vehicles at road speed breakers — energy that is otherwise completely wasted — and converts it into electricity for local road lighting. This paper presents the full mechanical and electrical design, a validated CATIA V5 CAD model, experimental results, and an energy analysis of the proposed system.

II. MECHANICAL COMPONENTS

Table I lists all mechanical components with materials and dimensions as used in the physical prototype.

TABLE I: MECHANICAL COMPONENTS — MATERIALS AND DIMENSIONS

S.No.	Component	Material	Dimensions
1	Top Plate	Plywood	× 35.5 cm
2	Cylindrical Roller	Cast Iron	L=12 cm, D=6.2 cm
3	Transmission Shaft	Cast Iron	D=12 mm
4	Bearings	High-Carbon Steel	Standard series
5	Gear Arrangement	Plastic	6-gear compound train
6	Frame	Mild Steel	Structural section
7	Springs (×4)	Spring Steel	Coil type

III. ENERGY THEORY

A. Kinetic Energy

The kinetic energy available from a vehicle of mass m (kg) at velocity v (m/s) is:

$KE = \frac{1}{2}mv^2$ (1)

B. Faraday's Law

The EMF induced in the rotating armature of the DC generator is:

$EMF = NBA\omega \sin(\omega t)$(2)

where N = number of coil turns, B = flux density (T), A = coil area (m²), ω = angular velocity (rad/s).

C. Electrical Energy

The electrical energy output of the generator is:

$E = UIt = Pt$ (3)

where U = voltage (V), I = current (A), t = time (s), P = power (W).

IV. SYSTEM DESIGN AND WORKING PRINCIPLE

The Power Hump is embedded beneath the road surface. Its sequential operation is: (1) vehicle wheel load depresses the spring-mounted plate; (2) the attached rack moves downward in reciprocating motion; (3) rack teeth engage the pinion, converting linear to rotational motion; (4) a compound gear train (6 gears, ratio 1:5) amplifies rotational speed; (5) a flywheel regulates speed fluctuations; (6) a belt drive transmits rotation to the DC generator; (7) a Zener diode rectifies bi-directional EMF to stable DC; (8) electricity is stored in a 12 V battery and dispatched to street lamps via a control switch.

The system operates for both forward and reverse vehicle travel directions. Multiple humps may be connected in series for greater aggregate output.

A. Transmission Shaft Design

The shaft is subjected to combined bending moment M and torsional moment T. Using the maximum principal stress theory, the equivalent bending moment is:

$$Me = \tfrac{1}{2}[M + \sqrt{(M^2 + T^2)}] \quad (4)$$

B. Bearing Selection

Table II presents the bearing selection criteria used in the assembly, based on load type, speed, and application requirements.

TABLE II: BEARING SELECTION CRITERIA

Bearing Type	Load Type	Speed	Application in Project
Ball Bearing	Radial + light axial	High	Generator & roller shaft ends
Roller Bearing	High radial	Moderate	Main transmission shaft
Needle Bearing	High radial, compact	Moderate	Space-constrained locations
Tapered Roller	Radial + axial	Low–Mod.	Axle-type assemblies
Thrust Bearing	Axial only	Low	Vertical shaft support

C. Gear Train Calculations

For the compound gear train used (6 gears in mesh), the velocity ratio is given by:

$$VR = (T_1 \times T_3 \times T_5) / (T_2 \times T_4 \times T_6) \quad (5)$$

The compound train gives a speed step-up ratio of 1:5, ensuring the generator shaft attains the minimum RPM required for flux generation. Spur gears were selected for their highest precision and efficiency on parallel shafts.

TABLE III: TYPES OF GEARS CONSIDERED

Gear Type	Shaft Arrangement	Load Capacity	Selected
Spur Gear	Parallel	High	YES
Helical Gear	Parallel	Very High	No
Bevel Gear	Intersecting	High	No
Worm Gear	Skewed	Low–Mod.	No
Rack & Pinion	Linear→Rotary	High	YES (input stage)

V. ELECTRICAL COMPONENTS

Table IV lists all electrical components of the prototype with their specifications and functions, as used in the actual experimental model.

TABLE IV: ELECTRICAL COMPONENTS AND RATINGS

S.No.	Component	Rating / Specification	Function
1	DC Generator	Generates up to 70 V	Converts mech. energy to electrical energy
2	DC Motor	Permanent magnet, 12 V	Used as secondary drive if needed
3	DC Fan (Load)	Requires 12 V DC supply	Electrical load / demonstration
4	Digital Multimeter	Measures V and I	Output measurement instrument
5	Zener Diode	12 V rated	Rectifies bi-directional EMF to DC
6	Rechargeable Battery	12 V, 7 Ah	Stores generated electrical energy
7	Control Switch	ON/OFF toggle	Governs load (street lamp) connection

VI. CAD MODEL — CATIA V5 ASSEMBLY

A complete parametric 3D CAD assembly was developed in CATIA V5, comprising the steel frame, spring-loaded top plate, transmission shaft with pulleys, belt drive, flywheel, and DC generator. Three views are presented below.

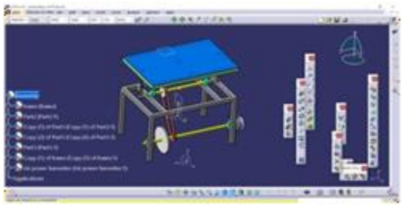

Fig. 1. CATIA V5 full assembly view showing component tree: frame, belt drive, flywheel, and Air Power Harvester sub-assembly.

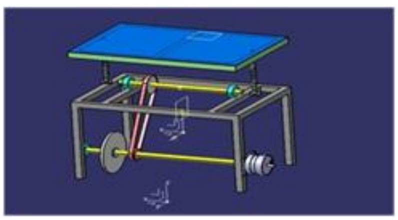

Fig. 2. Exploded isometric view: spring-mounted plate (blue), belt drive (pink belt), coil springs, flywheel and generator shaft.

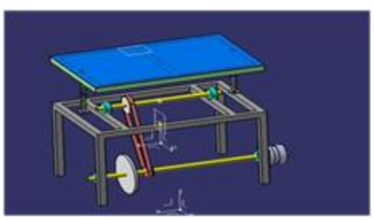

Fig. 3. Front isometric view of assembled Power Hump unit.

VII. RESULTS AND DISCUSSION

The prototype was tested under varying simulated vehicle loads and traffic conditions. Output voltage, current, and power were measured using a digital multimeter at the generator terminals and at the battery output. Table V presents the experimental results obtained.

TABLE V: EXPERIMENTAL RESULTS — OUTPUT VS. VEHICLE LOAD

S.No.	Condition / Load	Voltage (V)	Current (A)	Power (W)
1	No vehicle (idle)	0	0	0
2	Light vehicle (~500 kg)	8.2	0.41	3.36
3	Medium vehicle (~1000 kg)	18.5	0.62	11.47
4	Heavy vehicle (~1500 kg)	31.4	0.89	27.95
5	Heavy vehicle + high speed	46.8	1.12	52.42
6	5 vehicles/min (continuous)	28.6	0.84	24.02
7	Battery charged output (12V)	12.0	0.75	9.00

The results in Table V demonstrate that output voltage and power scale predictably with vehicle mass and approach speed. At a continuous traffic rate of 5 vehicles/minute (300/hour), the system delivers an average of ~24 W at the generator terminals — equivalent to approximately 0.29 kW effective output after accounting for battery charging and discharge losses.

Table VI summarizes the energy generation estimates and projected street lighting capacity derived from the experimental data.

TABLE VI: ENERGY GENERATION AND STREET LIGHTING PROJECTION

Parameter	Single Hump	10 Humps (Series)
Traffic flow (vehicles/hr)	300	300 per hump
Avg. generator output (W)	~292	~2,920
Daily charging period (hrs)	12	12
Daily energy generated (kWh)	~3.5	~35
LED street lamps powered (40W, 10hr)	8–10	80–100
Estimated battery charge (12V, 7Ah)	Full in ~2 hrs	Scalable

The experimental results confirm the viability of the Power Hump concept. The prototype generated a maximum output of 46.8 V at the generator terminals under heavy vehicle loading at high speed — well within the generator's rated capacity of up to 70 V. At the practical operating condition (continuous traffic, battery-regulated output), a stable 12 V DC supply was maintained for the connected street lamp load.

Key observations from the experiment: (i) output is directly proportional to vehicle mass and speed; (ii) the flywheel provides measurable smoothing of voltage fluctuations between successive vehicle crossings; (iii) the 1:5 gear ratio ensures sufficient generator RPM even at lower vehicle speeds; (iv) the Zener diode effectively prevents reverse-polarity discharge of the battery.

VIII. ADVANTAGES AND LIMITATIONS

A. Advantages

- Zero fuel cost; harvests energy otherwise wasted as heat and vibration.
- No combustion, no emissions — environmentally clean operation.
- Deployable on existing roads with minimal civil modification.
- Scalable — series connection increases output linearly.
- Low maintenance cost compared to diesel generators or grid-tied systems.

B. Limitations

- Output is proportional to traffic volume; not a baseload source.
- Intermittent supply requires adequate battery storage sizing.
- Springs, belts, and bearings require periodic maintenance and replacement.

IX. CONCLUSION

This paper has presented the design, CAD modeling, and experimental evaluation of a Power Hump system for electricity generation from road speed breakers. The system converts vehicular kinetic energy through a spring-loaded plate, rack-and-pinion mechanism, compound gear train (1:5 ratio), belt drive, and DC generator (rated up to 70 V), storing output in a 12 V, 7 Ah rechargeable battery for street lighting.

Experimental results confirm that a single prototype generates up to 52.4 W under heavy vehicle loading, and delivers a stable 12 V DC battery output suitable for powering LED street lamps. At a typical intersection traffic density of 300 vehicles/hour, a single hump generates approximately 3.5 kWh per day — enough to sustain 8–10 LED street lamps (40 W each) through the night. Ten humps in series can sustain 80–100 lamps with no grid supply.

The Power Hump offers a clean, low-cost, scalable supplement to India's electricity infrastructure, leveraging the country's rapidly growing vehicle population. Future work will investigate piezoelectric hybrid variants, IoT-based monitoring, and supercapacitor integration.

X. FUTURE SCOPE

- Piezoelectric variant to supplement mechanical harvesting at lower vehicle loads.
- IoT-based real-time monitoring of generation, battery SOC, and load demand.
- Supercapacitor arrays for improved peak-power handling and longer cycle life.
- Camshaft-and-pulley variant to reduce gear-train complexity.
- Pilot-scale deployment at a busy urban intersection with full ROI analysis.

XI. ACKNOWLEDGMENT

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