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OPTIMIZATION OF RUMBLE STRIPS AND PIEZOELECTRIC SENSOR

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Abstract - *This project investigates the potential of harvesting kinetic energy from rumble strips using piezoelectric materials, which convert mechanical vibrations caused by vehicle movement into electrical energy. Rumble strips, when subjected to the force of passing vehicles, generate vibrations that can be captured by piezoelectric sensors embedded within the strips. The integration of advanced materials such as Elastollan 1190A (TPU) and Sorbothane 70 Duro significantly enhances the efficiency of this energy conversion. Elastollan 1190A, with its high mechanical strength and flexibility, is employed to encase the piezoelectric elements, providing protection while optimizing the transmission of vibrations. Sorbothane 70 Duro, known for its superior damping properties, further improves the system by reducing energy losses from excess vibration and enhancing the overall power output of the piezoelectric sensors.*

By combining these materials, the project aims to create a more effective and durable energy harvesting system. Elastollan 1190A ensures that the piezoelectric components remain secure and functional under varying environmental conditions, while Sorbothane 70 Duro improves the energy conversion efficiency by absorbing unnecessary shock and vibration. This research focuses on optimizing the performance of kinetic energy harvesting systems, providing a sustainable method for converting waste energy into usable power. The outcome promises to contribute to energy-efficient technologies and the development of alternative energy sources, particularly for applications in transportation and road infrastructure.

Key Words: Piezoelectric Sensor, Rumble Strips, Finite Element Analysis, Elastollan, renewable energy

1.INTRODUCTION

In our daily lives, energy is all around us, often going to waste. For example, the heat from the sun, the wind blowing, or even the movement of vehicles on roads creates energy. Harnessing this energy helps us use it for useful purposes, like powering lights, running machines, or charging devices.

For this project, harnessing energy focuses on using the movement of vehicles over rumble strips to generate electricity. By capturing the kinetic energy from vehicles as they pass, we can turn it into power for things like streetlights, traffic signals, or even charging stations for electric vehicles. This approach not only reduces energy wastage but also supports sustainable transportation by powering essential infrastructure with clean energy. This is a smart and eco- friendly way to make better use of energy that's already being produced in our surroundings. Integrating energy-harvesting rumble strips into transportation systems can significantly improve energy efficiency. It ensures that the energy produced by vehicles is reused effectively, reducing reliance on traditional energy sources.

This is a smart and eco-friendly way to align transportation systems with energy conservation efforts and make better use of the energy being generated in our surroundings. Using rumble strips for energy conservation not only promotes sustainability but also helps reduce dependence on non-renewable energy sources.

By integrating piezoelectric sensors into road surfaces, particularly rumble strips, we can capture the energy generated by the movement of vehicles. As vehicles pass over these strips, the pressure from their tires causes the piezoelectric materials to produce electricity. This innovative approach to harnessing energy from roads contributes to creating eco-friendly, energy- efficient transportation systems for the future.
With continuous vehicular traffic on highways, this system operates around the clock, maximizing energy capture. It offers a sustainable solution that not only minimizes energy waste but also aligns with global efforts to reduce carbon emissions and transition towards renewable energy sources. By tapping into

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the abundant kinetic energy available on roads, this approach exemplifies how innovative technologies can transform everyday infrastructure into sustainable energy systems.

In conclusion, The United States (US) has the largest road network in the world, spanning 6.58 million kilometers. It has also implemented measures to conserve energy on roads by using:

- **Piezoelectric sensors** to generate electricity from the pressure of moving vehicles.
- **Solar panels** to capture sunlight and produce electricity.
- **Solar collectors** to gather and utilize heat energy from the sun.

India has the second-largest road network in the world, spanning 5.89 million kilometers. The country is exploring innovative ways to generate energy from roads, such as:

- **Kinetic roads** that capture energy from the movement of vehicles.
- **Vertical axis wind turbines** that produce electricity using wind created by passing vehicles.

1.1 Problem and Solution Statement

The potential of energy-harvesting rumble strips, their implementation remains limited due to challenges such as low energy output from existing materials, high maintenance under heavy traffic and harsh weather, and the need for additional equipment to utilize the generated energy. In India, factors like mixed traffic, poor road conditions, and inadequate infrastructure further complicate deployment. These issues highlight the need for more durable materials, optimized designs, and site selection strategies before practical implementation can be realized.

The use of advanced materials such as PZT-5H and PZT-PVDF films for sensors, and durable composites like Elastollan 1190A and Sorbothane 70 Duro for the strip structure, can significantly enhance energy output and durability. Protective coatings like SikaCor 4000 primer can extend system life under heavy traffic and harsh weather. Integrating energy storage systems such as batteries ensures continuous functionality during low traffic. Strategic placement in high-traffic zones, combined with hybrid systems that incorporate solar power, can improve reliability. Additionally, government incentives and funding support are essential for reducing installation costs and enabling large-scale deployment.

1.2 Motivation and Scope of the Proposed Work

The increasing need for sustainable energy solutions in transportation has driven interest in harnessing kinetic energy from vehicles. Energy-harvesting rumble strips offer a promising approach by converting vehicular motion into electrical energy using piezoelectric sensors. This energy can power essential infrastructure like streetlights, traffic signals, and EV charging stations—promoting energy efficiency and reducing reliance on non-renewable sources. The technology contributes to smarter road systems and aligns with global efforts to reduce carbon emissions.

With India having the world's second-largest road network, this solution is particularly relevant. The use of piezoelectric sensors, which have a 5–7year lifespan and require minimal maintenance, presents a durable and low-maintenance method for energy generation. By capturing otherwise wasted kinetic energy, this system supports the transition to greener, more efficient transportation networks.

This project focuses on developing and evaluating an energy-harvesting system using piezoelectric-embedded rumble strips tailored to Indian road conditions. It aims to harness the kinetic energy from high-traffic areas such as highways, toll plazas, and urban roads to power transportation infrastructure. The work will address challenges specific to India, including mixed traffic, varying loads, and infrastructure limitations.

Key focus areas include optimizing energy output, improving sensor durability, and ensuring cost-effectiveness for large-scale deployment. The project will also explore energy storage solutions and hybrid systems to maintain consistent power supply. Ultimately, it supports India's renewable energy goals and smart city initiatives, contributing to a cleaner, energy-efficient future.

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2. METHODOLOGY

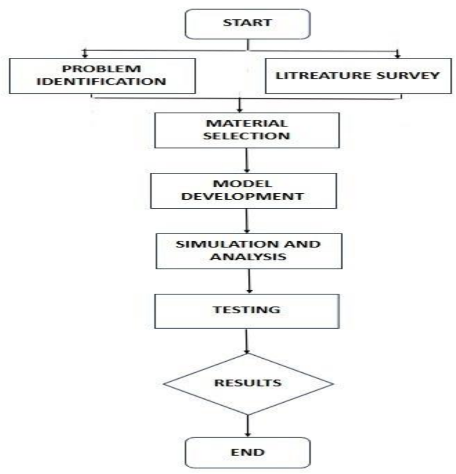

Figure.1 Flowchart

2.1 MATERIAL COMPONENT

- **ELASTOLLAN 1190A**

Elastollan 1190A, a thermoplastic polyurethane, is prized for its excellent abrasion resistance and flexibility. These features make it ideal for enduring repeated vehicular loads with minimal wear. Its elasticity facilitates effective vibration absorption and transfer to the piezoelectric layer beneath. Moreover, it demonstrates resilience to UV radiation, weathering, and chemical exposure, making it particularly suitable for outdoor use in applications like rumble strips.

- **SORBOTHANE 70 DURO**

This viscoelastic material is renowned for its exceptional vibration-damping and shock-absorbing qualities. The 70 Duro variant strikes an optimal balance between hardness and energy dissipation, effectively managing high-frequency vibrations. This ensures efficient energy transfer to the piezoelectric layer while shielding other components from excessive stress. Sorbothane maintains its damping efficiency across a wide temperature range, guaranteeing stable performance in diverse environmental condition.

- **PZT DISC**

Known for its outstanding piezoelectric properties, PZT disc sensor features a high piezoelectric charge constant, enabling effective conversion of mechanical stress into electrical energy. Its high Curie temperature (195°C) and excellent dielectric characteristics make it suitable for variable thermal conditions and high-load applications. PZT disc sensor is highly durable under mechanical strain, ensuring reliable performance in dynamic environments like rumble strips.

- **BONDING MATERIAL & WIRES**

Flex Kwik adhesive is used to bond components securely, providing quick setting and strong hold and Copper connecting wires are used ensure efficient electrical conductivity between the materials.

2.2 DESIGN AND ANALYSIS

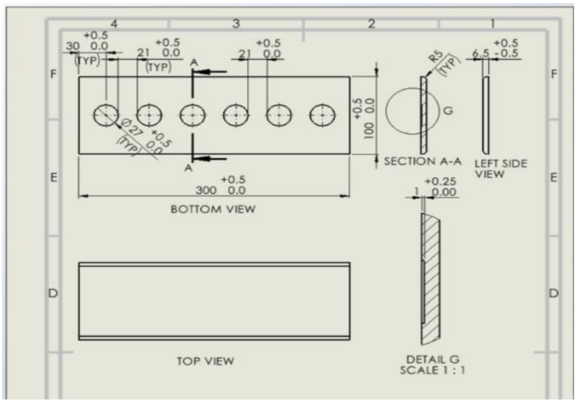

Figure.2 2D Design Of Strip In Rumble Strips

The proposed layer structure for the piezoelectric energy harvesting system integrated into rumble strips is designed to balance energy efficiency, durability, and protection. Each layer serves a specific function to optimize performance under mechanical strain from vehicle traffic and to ensure longevity. Here's the layer of materials:

1. **Base Layer**: Sorbothane 70 Duro of 25.4mm thickness.
2. **1st Layer**: PZT Disc sensor of 0.5mm thickness.
3. **2nd Layer**: Elastollan 1190A of 6.5mm thickness.

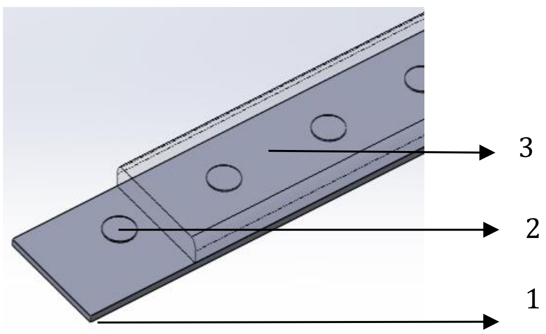

Figure.3 Layer Of Materials In 3D

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Table of Design Points

	A	B	C	D	E	F
1	Name	P5 - Force Magnitude	P6 - Static Structural Environment Temperature	P1 - Total Deformation Maximum	P12 - Maximum Principal Stress Average	P13 - Equivalent Stress Average
2	Units	N	C	m	Pa	Pa
3	DP 0 (Current)	-9.81	22	9.7282E-06	46147	86655
4	DP 3	-14715	22	0.014592	6.9221E+07	1.2998E+08
5	DP 4	-24525	22	0.02432	1.1537E+08	2.1664E+08
6	DP 5	-44145	22	0.043777	2.0766E+08	3.8995E+08
7	DP 6	-1.1772E+05	22	0.11674	5.5376E+08	1.0399E+09
8	DP 7	-1.7058E+05	22	0.16916	8.0242E+08	1.5068E+09
9	DP 8	-4905	22	0.0048641	2.3074E+07	4.3328E+07
10	DP 9	-9.81	-40	9.7282E-06	46147	86655
11	DP 10	-1962	22	0.0019456	9.2294E+06	1.7331E+07
12	DP 11	-11772	22	0.011674	5.5376E+07	1.0399E+08

Figure.4 Rumble Strip simulation in ANSYS

To assess the mechanical response and energy harvesting potential of the material used in the rumble strip, simulations were conducted under dynamic loading conditions representing vehicle weights of:

- Two-wheeler = 200kg
- Three-wheeler = 500kg
- Light commercial vehicle = 4500kg
- Bus = 12000kg
- Trucks:
  - Medium load = 18000kg
  - Heavy load = 45000kg
- Passenger cars:
  - Hatchback = 1200kg
  - Sedan = 1500kg
  - SUV = 2500kg

These weight categories were chosen to replicate a range of real-world scenarios, from light two-wheelers to heavy automobiles. The simulations analyzed the material's stress distribution, strain energy density, and deformation behavior under these loads. This multi-load analysis reinforces the design's adaptability and its potential scalability for diverse vehicular environments. Also, the simulation was extended to include environmental conditions, with temperatures ranging from -40°C to 50°C

2.3 FABRICATION

The rumble strip specimen was fabricated using the injection molding process, utilizing Elastollan 1190A, a thermoplastic polyurethane (TPU) known for its high mechanical strength, abrasion resistance, and flexibility. The process was selected due to its suitability for mass production and its ability to accurately reproduce complex geometries, such as the integrated pockets within the rumble strip.

1. MOLD DESIGN

(i)MOULD DIE TOP

Embossment Design: The mould has a flat rectangular plate (600 mm x 100 mm x 6.5 mm) with embossment feature for 6 circular outward features.

Pocket Geometry: These are integrated into the mould as shallow indentations 0.5 mm deep and 27 mm in diameter, spaced at 21 mm intervals.

Mold Material: Typically, MS (Mild steel) plates and SS (Stainless Steel) plates are used for Elastollan, with polished finish to prevent material sticking.

Gate and Runner System: Channels are designed to guide molten material into the mould cavity efficiently.

(ii)MOULD DIE BOTTOM

Cavity Design: The mould has a flat rectangular plate (600 mm x 100 mm x 6.5 mm) with depression for 6 circular pockets.

Pocket Geometry: These are integrated into the mould as shallow indentations 0.5 mm deep and 27 mm in diameter, spaced at 21 mm intervals.

Mold Material: Typically MS (Mild steel) plates and SS (Stainless Steel) plates are used for Elastollan, with polished finish to prevent material sticking.

Gate and Runner System: Channels are designed to guide molten material into the mould cavity efficiently.

2.MATERIAL PREPARATION

Material Used: *Elastollan 1190A* pellets (thermoplastic polyurethane). Pellets must be dried (typically at 80–100°C for 2–4 hours) to remove moisture and prevent hydrolysis. Dried pellets are loaded into the hopper of the injection moulding machine. Typically for Elastollan 1190A, melting temperature for injection moulding is 215°C

3.MELTING AND INJECTION

The material is conveyed through a heated barrel by a rotating screw. Barrel temperatures: ~200–230°C (specific for Elastollan 1190A). As the screw rotates, it shears and melts the pellets into a homogeneous molten mass. The screw moves forward like a plunger to inject the molten Elastollan into the mould cavity through the sprue and runners.

3. CONCLUSIONS

This study analyzed the performance of a piezoelectric embedded rumble strip prototype, which demonstrated effective voltage generation under simulated vehicular loading. The layered structure—comprising Elastollan 1190A for mechanical flexibility and durability, Sorbothane 70 Duro for damping and force transmission, and embedded PZT disc sensors for energy conversion—enabled efficient stress transfer and consistent sensor activation. The PZT sensors produced repeatable voltage outputs proportional to applied loads, with series connection enhancing overall signal strength. The system showed mechanical stability under cyclic deformation, confirming its suitability for long-term roadside use. This multifunctional strip not only served as a driver alert mechanism but also harvested kinetic energy, offering potential for smart infrastructure applications such as self-powered traffic sensors, and vehicle counters.

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