Electricity generation from modular piezoelement array in vehicle Tire

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Abstract - T*his research investigates the potential of utilizing piezoelectric materials to harvest energy from vehicle wheels, capitalizing on their unique ability to convert mechanical energy into electrical energy. Through experimental analysis, we quantify the energy output of piezoelectric materials affixed to vehicle wheels and compare it with the energy requirements of various electronic devices. Our findings demonstrate substantial promise for piezoelectric energy harvesting to power a wide array of devices, thereby reducing reliance on conventional power sources. Moreover, the study evaluates the efficiency of energy harvesting systems in capturing and converting mechanical vibrations from wheels, highlighting their practicality and versatility across different applications. Additionally, we discuss the environmental benefits, emphasizing the role of this technology in mitigating carbon emissions and promoting sustainable engineering practices. Looking ahead, the research underscores the need for further exploration and optimization of piezoelectric energy harvesting technologies to advance renewable energy solutions and address global energy challenges effectively.*

Key Words: **Piezoelectric material, module, array, tire, electricity, energy**.

1.INTRODUCTION

There is an escalating demand for energy resources globally as societal development and expansion continue unabated. This heightened demand has amplified concerns regarding the depletion of conventional energy resources, prompting a search for alternative, sustainable solutions. Modern society has increasingly embraced non-traditional energy sources such as solar cells, wind energy, hydroelectric power, geothermal energy, and biogas plants. However, the burgeoning automotive sector, particularly with the advent of Hybrid Electric Vehicles (HEVs) and Electric Vehicles (EVs), presents a unique challenge. The immense energy required to power these vehicles necessitates innovative approaches to energy utilization. Piezoelectric materials and their effect play a pivotal role in addressing this challenge.

The piezoelectric effect, a phenomenon wherein certain materials generate electric charge in response to mechanical stress, holds immense promise for sustainable energy generation. As vehicles traverse roadways, the interaction between tires and the road surface creates mechanical vibrations, presenting an untapped source of energy. Harnessing this energy through the integration of piezoelectric materials within vehicle tires offers a compelling solution to address the pressing need for renewable energy sources. This research explores the potential of utilizing the piezoelectric effect to convert mechanical vibrations from tire-wheel interactions into electrical energy. By investigating the fundamental principles of piezoelectricity and its application in energy harvesting, this study aims to elucidate the feasibility and efficacy of employing piezoelectric materials to power various electronic devices, thus reducing reliance on conventional energy sources and advancing sustainable engineering practices. Through experimental analysis and theoretical modeling, we aim to quantify the energy output of piezoelectric systems integrated into tires and assess their potential impact on mitigating carbon emissions and promoting environmentally friendly transportation technologies. This introduction sets the stage for our investigation into the transformative potential of harnessing vehicular vibrations for sustainable energy generation using piezoelectric materials.

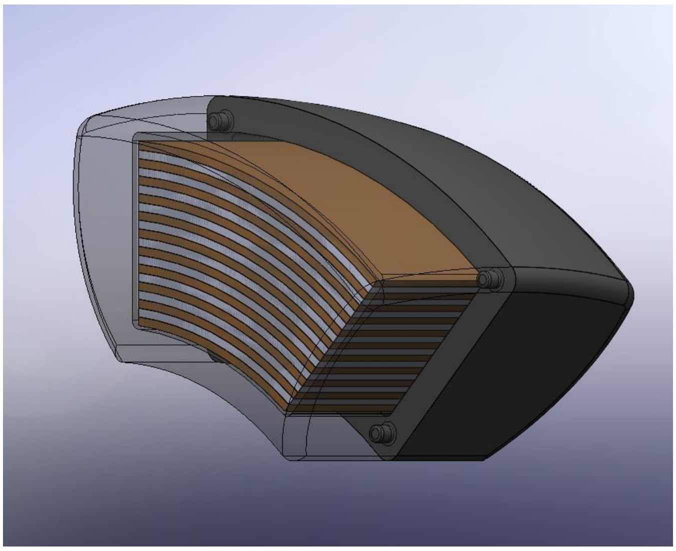

Fig -1:Piezoelectric module

1.1 LITERATURE REVIEW

The concept of Piezoelectric energy harvesting has been around for some time. Efforts have been made to integrate this technology with maximum efficiency to harness wasted energy.

Previous research on piezoelectric energy harvesting from vehicular vibrations in automobile wheels are used as follows:

Aditya Pandey , Tejas Bansal , Amey Konde , Rushikesh Giri , Sarvesh Gandhi ``Energy Generation in Tyres using Piezoelectric Material”. A study done here emphasized the importance of improving the piezoelectric modules either by efficiency or simply number of modules used. [1]

Ayan Bhattacharya “Piezoelectric Energy Harvesting In Automobile Wheels” introduced the concept of using piezoelectric modules to collect energy from vehicle wheels. It is a widely known subject but the inefficiency of the modules must be highlighted. [2]

Muhammad Kamran, Dr. Raziq Yaqub, Dr. Azam ul Asar “Autonomously Battery Charging Tires For EVs Using Piezoelectric Phenomenon” proposed more interesting applications of this technology with the rise of EV technology using batteries. [3]

2. METHODOLOGY

The research methodology encompasses the design, implementation, and evaluation of a piezoelectric energy harvesting system integrated into vehicle tires. Eleven modules, each housing nine arrays, are designed to facilitate energy capture during tire rotation. Each module is engineered to ensure that only one module makes contact with the road surface at any given time, optimizing energy harvesting efficiency. Piezoelectric sensors are embedded within each array to capture mechanical vibrations induced by tire-road interactions. This involves mounting the modules and arrays onto the inner surface of the tire and then mounting the tire onto a test rig or vehicle wheel assembly.

The electrical signals generated by the piezoelectric sensors are transmitted to electronic filters to remove noise and unwanted frequencies, enhancing signal quality. Processed signals are directed to a battery storage system for energy storage and management. Data analysis techniques are employed to evaluate the performance of the system, including statistical analysis and comparison with theoretical predictions. Optimization strategies are explored based on analysis results, and potential applications of the developed system are discussed to guide future research endeavors.

3. MATERIAL SELECTION

In our design, the choice of material for housing the piezoelectric sensors (PZTs) within the tire space is crucial to ensure optimal performance while minimizing weight. After careful consideration, High Density Polyurethane (HDU) foam emerges as the preferred option. HDU foam, characterized by its higher density compared to standard polyurethane foam, offers several advantageous properties for our application.

The manufacturing process of HDU foam involves mixing isocyanate and polyol chemicals along with additives such as blowing agents, catalysts, and surfactants. This mixture expands and cures into a rigid, closed-cell foam with a smooth, uniform surface, ideal for accommodating the PZTs within the tire space. HDU foam boasts a lightweight nature, making it well-suited for our purpose of covering a large volume without significantly increasing the overall weight of the tire. Additionally, its high strength and durability ensure long-term reliability in demanding operational conditions.Furthermore, HDU foam exhibits resistance to water, insects, and rot, enhancing the longevity of the tire housing.

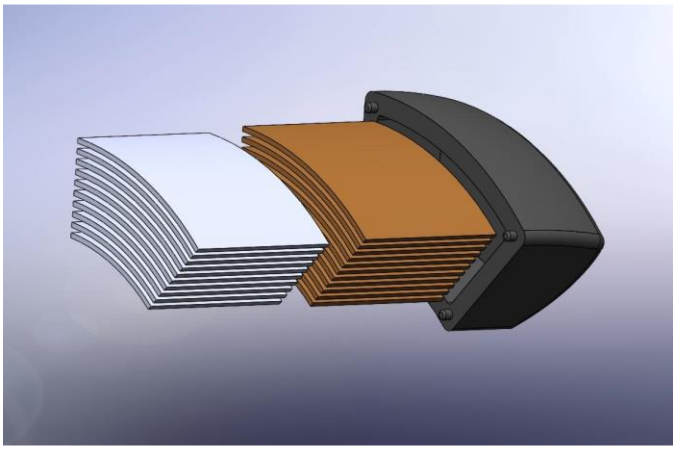

Fig -2:Piezo-electric module exploded view.

The material's ability to be manufactured in various densities allows for customization according to specific project requirements. Higher density variants of HDU foam, ranging from 350-480 kg/m^3, are commonly utilized for structural and load-bearing applications. This density range provides the necessary strength and durability to support the PZTs within the tire space effectively. In terms of applications, higher density HDU foam finds extensive use in composite material manufacturing, such as fiberglass and carbon fiber, where it serves as a lightweight and durable core material. Additionally, it is employed in the production of molds, patterns, and tooling across diverse industries including aerospace, automotive, and marine.The increased density of HDU foam enhances its resistance to compression, enabling it to support heavier loads without deformation or collapse. Notably, HDU foam exhibits resilience against impacts and stress, contributing to its overall durability and reliability in our application.In conclusion, HDU foam emerges as a versatile material choice for housing the PZTs within the tire space. Its durability, versatility, and ease of use make it well-suited for our energy harvesting system, ensuring optimal performance and longevity in various operating conditions.

4. CALCULATION

4.1 DIMENSION OF PZT

a.Length (l)

The dimensions of a tyre for Tata Nexon 215/60 R16, this means the width of tyre is 215mm. When we give 20mm thickness of sidewalls, we are left with 175mm space. In this space we will be filling the material which will have slots of 150mm for holding PZT modules. Hence, the desired length of modules will be 150mm.

b.Width(w)

By assuming the availability of PZT we have taken the width of 30mm.

c.Number of Arrays(n)

Roughly the outer diameter of the array is 300mm and We intend to fit 4 PZT modules in one slot, hence the width of a slot is 4 x 30=120mm. Providing some clearance we will need 130mm on the narrow end (radius of 203mm at rim). This gives us an angle of 0.64 rad, dividing 2pi by this angle we get approximately 9 arrays. Each array has 9 slots for PZTs.

d.Thickness(t)

The energy generated by a piezoelectric plate is dependent on the thickness of the plate, but with increase in the thickness, brittleness also increases. Therefore, an optimum thickness should be selected for the most efficient and physically viable power generation. Piezoelectric plates of 1 mm thickness have been finalized.

4.2 MATHEMATICAL CALCULATION

a.Division of vehicle load

Kerb Weight of the vehicle = 1400kg

Weight of passengers = (5 × 85) = 425kg.

Since the vehicle is a TATA Nexon EV which is a 5-seater and assuming that the weight of each passenger is 85kg.

Gross weight = Kerb weight + Weight of passenger

= (1400 + 425) kg = 1825 kg

Taking the weight distribution of the vehicle as (50-50),

The load on the front and rear wheels are:

Front wheels = 50% of 1825kg = 912.5kg

Rear wheels = 50% of 1825kg = 912.5kg

Since the load on the front and rear wheels is same,

Load on each wheel = 912.5 / 2 = 456.25kg.

Force on each wheel=456.25*9.81=4475.8125N

b.Contact patch area

It is the area which will be in contact with the surface when the vehicle is at rest or in motion. We assume the area of contact by using the cad representation is 18000mm^2

c.Voltage

The voltage generated is directly proportional to the induced mechanical stress (σ). Therefore, Open Circuit Voltage (OCV) of the ceramic plates is calculated.

Induced mechanical stress (σ) is:

σ = Force on each ceramic plate/Area of the ceramic plate

$\sigma = 4475.8125 / 4\times (0.15 \times 0.03)$

$\sigma = 248656.25$ N/m2

Therefore, the generated open circuit voltage is:

O.C.V = $g33 \times \sigma \times t$

O.C.V = 24×10-3 × 248656.25 × 0.002

O.C.V = 11.9355 v

As we have created 9 slots each slot generates voltage 11.93 v approx. for voltage amplification

We had connect all voltages in series so now total voltage is 9*11.93=107.37v in each array.

So now for increasing the current rate we have arranged arrays in parallel so there will be an amplification of current. So Total voltage output is 107.37 v from one array.

d.Charge Density

Charge Density is defined as the amount of electric charge per unit length.

Charge Density = d33 × σ

Charge Density = 390 × 10-12 × 248656.25

Charge Density = 0.96× 10-4 N/Vm

Since the voltage generated and the charge density of the plate is known, the charge on each plate is:

Charge on each plate = Charge Density × Area of a single plate Charge on each plate = 0.96 × 10-4 × (0.15 × 0.03)

Charge on each plate = 4.275× 10-7 Nm/V

f.Power Output

To calculate the Power generated by a single plate:

Power = Voltage × Charge Power

= 107.37 × 4.275*10^-7

Power = 45.900µW .

There are a total 9 arrays of piezoelectric slots in a single tire.

Therefore, the power generated by a single rotation of a tire is:

Total Power for 9 plates = 9*45.900 = 413.1µW per rotation. . Assuming that the vehicle is being driven at a velocity of 80km/hr i.e. 22.22m/sec.

For 22.22m/sec,

RPM= velocity/circumference of the tire

RPM = 22.22/π×0.6644 = 10.64 rotation/sec

Power output per second per wheel = 10.64×413.1

Power output per second per wheel = 4395.38µW

= 4395.38 x 4

= 17581.52µW

=17581.52× 3600

= 6,32,93,472 µW

=63.293Wh

Power output from the vehicle is 63.293Wh

4.3 HEAT GENERATION

In piezoelectric energy harvesting systems, heat generation within the piezoelectric material occurs alongside the conversion of mechanical stress into electrical energy. This phenomenon is influenced by material properties as well as the frequency and amplitude of mechanical stress applied, under high frequency, they generate significant heat due to elastic, dielectric and piezoelectric losses. Factors including operating conditions and device configuration also impact heat dissipation and overall system efficiency. While piezoelectric materials offer significant potential for energy conversion, the presence of heat generation necessitates careful consideration to optimize system design and performance and mitigate energy losses. Further research into heat generation in stressed conditions, management strategies and material design is essential to enhance the efficiency and practical viability of piezoelectric energy harvesting technology.

5.ELECTRICAL

An AC to DC adapter is an indispensable device that facilitates the transformation of alternating current (AC) from a standard wall outlet into direct current (DC) suitable for powering electronic devices. Typically converting 120V AC to 12V DC, this adapter undergoes a multi-stage conversion process to achieve its functionality. Initially, the AC voltage is stepped down to a lower voltage, typically around 12V, through a transformer. Subsequently, a diode bridge rectifies the AC voltage into pulsating DC, which is then smoothed using a capacitor to eliminate ripples, resulting in a more stable DC voltage.

Finally, a voltage regulator ensures the output voltage remains constant at 12V, regardless of fluctuations in the input voltage or variations in the load. This comprehensive conversion and regulation process enables the AC to DC adapter to reliably power electronic devices requiring a 12V DC power supply.

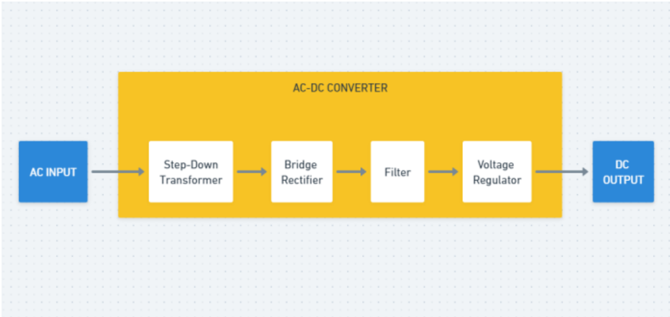

Fig -3:Block diagram of AC to DC converter.

6.DISCUSSION ABOUT OBTAINED RESULT

1.Piezoelectric sensors serve as key components in energy harvesting, leveraging the alternating/pulsating force from vehicle wheels to power various devices.

2.Powering lithium-ion batteries with a 48V capacity, suitable for electric two-wheelers.

3.Capturing energy for sale to power plants servicing electric vehicles.

4.Under typical operating conditions, such as a vehicle traveling at 80 km/hour:The energy harvesting system generates approximately 69.239 Wh of energy.This output can extend the range of vehicles like the Tata Nexon EV by approximately 1 km for every 80 km driven per hour.

5.These findings underscore the practical feasibility and potential impact of piezoelectric energy harvesting technology in enhancing the efficiency and range of electric vehicles, thereby advancing sustainable transportation solution

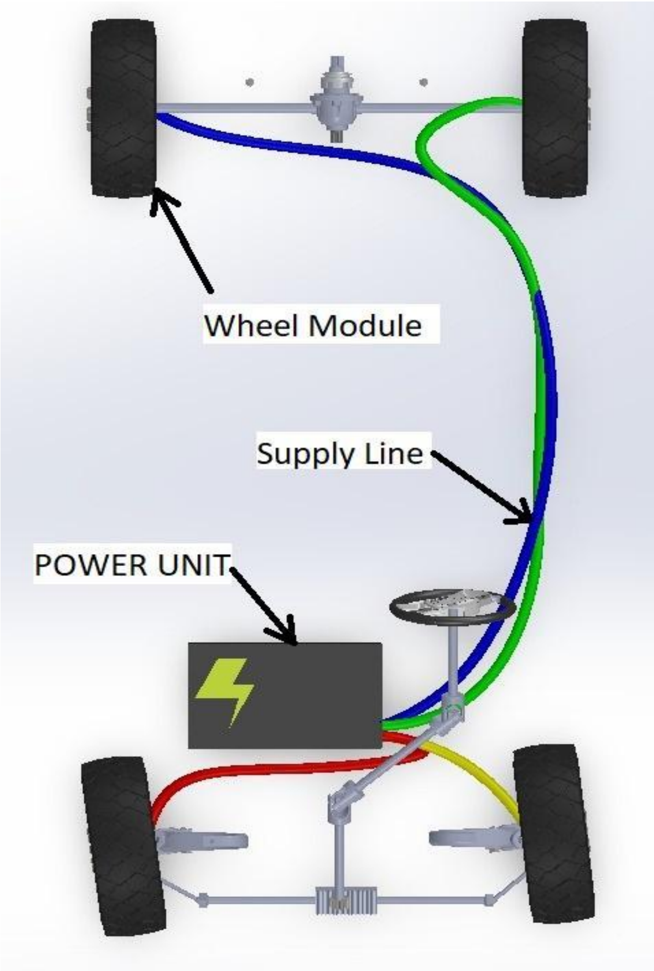

Fig -4:Vehicle system integrated with wheel-module.

7.CONCLUSION

While the research demonstrates that the piezoelectric energy harvesting process alone may not generate sufficient energy to fully power a vehicle, it presents a valuable opportunity to extend the range of existing vehicles. This system exhibits versatility with a myriad of potential applications, promising to transform the landscape of electric vehicles. Moreover, the study underscores the imperative for advancements in material selection for piezoelectric sensors to enhance their efficiency and effectiveness. Overall, the research underscores the transformative potential of piezoelectric energy harvesting technology in bolstering the efficiency and range of electric vehicles, thereby contributing to the advancement of sustainable transportation solutions.

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