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Eco-friendly Vibration Energy Harnessing in Conventional Two-wheeler and Electric Vehicle

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Abstract

Energy can neither be created nor destroyed but transforms from one form to another form. Energy harnessing is the process where the control and make use of natural ways such as load applied, free vibrations are analysed, captured and transformed to get low amount of voltage. The main aim of energy harnessing is to use eco-friendly vibrations to charge low electronic devices where there is no other way of available power sources like in remote locations and undersea applications. Specifically, the energy harnessing used in rechargeable dead batteries and improves by boost converter and to power low electronic devices, for charging mobiles. Piezoelectric materials are specifically chosen because of its dual nature of converting mechanical strain energy captured by vibrations into electrical charge and vice versa means converts applied electrical energy in to mechanical strain energy. This study suggests examining and testing a vehicle suspension system which was connected by the energy harnessing circuit that was designed, modelled and tested. Primarily analyses the kinetic energy absorbed in conventional Glamour bike (BS6) and later by Hero NYXe5 electric vehicle (EV) in running condition and observes the voltage generated based on the vibrations developed over the distance travelled in kilometres under the application of loads , the voltage generation is by the kinetic energy in the form of vibrations and are converted using piezoelectric materials through rectifier circuit, later harvest the energy get in dead rechargeable battery of 6V, 12V and improves by using the boost converter and the harvested voltage helps to recharge smart phones, air buds, low powered electronic devices. More the number of piezoelectric coils the higher the voltage can be harnessed. Finally focusses on incorporating nanomaterials in the design of piezoelectric energy harvesting system due to the unique properties of nanomaterials at the nanoscale to enhance mechanical and electrical properties and compared the obtained output voltage using PZT (Lead zirconate titanate) coils to PVDF (Polyvinylidene fluoride)-PZT nanocomposite film even for small application of force produces high voltage recommends the optimal solution of choosing nanocomposites.

Keywords

Energy harnessing, Piezoelectric coils, Circuit diagram, Boost converter, Polyvinylidene fluoride-lead zirconate titanate nanocomposite film

Nomenclature

C is Capacitance; $€_0$ is Electrical permittivity of material; Q is Electric charge; D is Electric charge density of material; F is Applied force; V is Voltage; A is Area of material; a is Acceleration due to gravity; W is Weight of the bike; W1 is Weight of one person; W2 is Weight of two person; w is Kerb weight of bike; N is Speed of rotation; T is Total torque applied; and n is Number of coils.

Introduction

In vehicle suspension system due to perpendicular vibrations on uneven roads, speed breakers can transform to electrical energy using various ways of harnessing techniques such as mechanical, chemical, optical, thermal, nuclear, and electrical transformation mechanisms. Among those adapted theme-chanical to electrical transformation of energy for achieving the objectives of harnessing unwanted and wasted vibrational energy while vehicles moving on uneven roads, speed breakers, obstacles on roads, to make use of harnessed voltage in the form of 6V, 12 V lithium ion rechargeable dead battery to power low electronic devices like mobile charging, LED's display lights etc. The adoption of automobiles as a means of transport has been around for a very long era, but the global impacts caused by excessive use of gasoline and industrial emissions are now a global issue.

The advancement of automobile technology for eco-friendly vehicles, such as hybrid electric vehicles that use electric power to address these global impacts, is progressing. Optimizing fuel usage is always a target [1] proposed a hybrid energy harvesting system by designing and testing which is suitable to solve power supply problem of low electronic components while sharing the bicycles [2]. The high working efficiency over various excitations proposes a spring-based bistable energy harvester (SBEH) in two different configurations (SBEH sup and SBEH sub) through different modulations [3]. A rectifier based electromagnetic energy harvester has been proposed in order to transform low frequency vibrations for bicycle by translating linear motion to bidirectional rotation and finally to unidirectional which is attached to the electrical generator to store electrical energy in super capacitor and light up LED [4]. In order to generate self-sustainable roadside electrical power by using several harvesting technologies were studied and reviewed based upon from the stage of prototype development to economic considerations of each technology which helps the young researchers to understand clearly. [5] proposes two methods of electrical power harvesting first one is using capacitor and later by using nickel metal hybrid battery and based on the pros and cons suggests the use of battery second one is better than first one that is capacitor this primary idea plays a key role for my research work [6] without using any conventional way like fuel the unwanted vibrations which may cause damage to the structures by avoiding the sound pollution a new technique was proposed using piezo sensors which is the main motivation for my research work done [7]. The literature reviewed by considering the power output performance based on three different energy conversions like theory, methods, and potential applications were summarized so that one can choose one among them for their proposed work [8]. Compared the theoretical and software based Finite Element Analysis of front suspension spring results from various analytical methods were examined and suggested the optimum result of the spring coil [9]. The structural analysis of shock absorber is done simulation by considering three materials structural steel (ASTM A230), stainless steel (ASTM A313) and alloy steel (ASTM A231) using ANSYS by importing the 3D model developed by CATIA V5 is done first and later analysis is carried out by varying different wire diameters proposed ASTM A231 as desired spring material based on reduced weight and deformation stresses. [10] developed a piezoelectric bike which can harvest voltage by pedalling using a micro energy harvester with suitable electrical circuit consists of transducer is an electro-mechanical converter which converts mechanical vibrations into EMF. [11] suggests that the suspension model of any vehicle cannot get effected by the position of centre of gravity by comparing the models three types of suspension systems that is quarter, half and full vehicle suspension system integrated with regenerative shock absorbers based on the same baseline vehicle on different road classifications such as [A, B, and C] [12]. In order to improve efficiency of energy harvesting by reducing the impact forces during oscillations an unique motion mechanism called mechanical motion rectifier to translate suspensions oscillatory motion to unidirectional motion an innovative design of regenerative shock absorbers was suggested [13] analysed using a Honda Passion bike as a base mode for different load conditions to check the deformation of suspension system under various classification of roads. [14] a detailed review on various methods of energy harvesting were discussed based on their advantages and disadvantages proposed the gaps and unresolved challenging issues which makes for future research was suggested and research focuses on the gap of comparing the low power efficiency of conventional and electrical vehicle harnessing using piezoelectric materials. [15] reviewed based on different configurations of PEH's analysis on different scales with several piezoelectric materials Normalized Power Density (NPD) was introduced to compared and primary presented NPD-volume graph based upon the literature collected [16]. Demonstrated a new technique for different mass weights as proofs of various lengths of piezoelectric cantilever a piezoelectric self-tuning energy harvester was designed and predicted [17]. Theoretical and simulation analysis has been done and compared the results of natural frequencies for two kinds of piezoelectric cantilevers beams using ANSYS software [18]. An unimorph piezoelectric energy harvester was designed and compared the results by varying lengths triangular and rectangular shapes using MATLAB and COMSOL Multiphysics software [19]. Boley's iterative method was extending the iterative method for piezoelectric beams for comparing the thickness to length ratio using 2D stress analysis [20]. Targets the nonlinearities in a piezo magnetoelastic structure under random variations with theoretical simulations which influence the energy harvesting [21]. Experimentally presented micro energy harvester from silicon substrate with aluminium nitride elements with multiple DOF has been designed and tested with in low ambient vibration frequency range considering chip as a proof mass [22]. Modelling of composite beams with multi-layer along with piezoelectric energy harvesters [23]. Bimorph piezo electric cantilever beam is used to study the design parameters for simple geometries under specific frequency to achieve maximum power output [24]. Provided a comprehensive review on simple fabrication of piezoelectric nano-generators with composite structural design, the energy conversion performance of nanogenerators based on nanowires for improving energy harvesting efficiency in self-powered systems [25]. Proposed piezoelectric effects on single walled and multi walled piezoelectric materials using atomic force microscopy, analysed and determined the piezoelectric coefficient for different weight percentages, stated that single walled carbon nanomaterial performance is lower than multi walled carbon nanomaterial which results of low mechanical compliance [26]. Reviewed the types, principles and applications of piezoelectric nanomaterials in emerging fields of electro genetics, electromechanical conversion effects, artificial intelligence and biomedical [27]. Introduces the principles and applications of piezo potential of piezoelectric materials that are non-ferro electric, ferro electric and pyro electric coupling effect used for material removal, selection deposition, material evolution, piezo catalysis on metal surfaces [28]. Studied fabrication of piezoelectric composites using three types of piezoelectric nanomaterials and two types of urethane matrices in addition with multi walled nano tubes, investigated the relationship between the characteristics of different materials with the generated output voltage [29]. Reviewed on various types of piezo materials, their characteristics, chemical processes, applications, performance depending upon synthesis methods, Polarization, shape, size, conditions and focuses that for energy harvesting using piezoelectric materials realizes a simultaneous approach of piezo separator approach by combining energy harvesting and storage of self-powered cells [30]. Integration of conventional power sources and batteries with micro/nano systems cannot be done but replacement or recharging periodically due to bulk size and weight leads the best solution of energy harvesting technology and focussed on various ceramics like PZT, ZnO, PVDF, $BaTiO_3$ by mentioning the advantages [31]. Introduces the classifications, applications, parameters of piezoelectric mechanism at high temperatures which helps the researchers to design and explore the study of piezoelectric materials at high temperature [32].

This work focuses on the phenomenon of transforming mechanical to electrical energy by using piezoelectric coils attached to the two wheelers and improves using simple harnessing piezoelectric circuit which can be stored in lithium-ion rechargeable dead battery which can be used to power low electronic devices. This analysis will help in harnessing the vibration energy even if the capacitor discharges high voltage, this harnessed voltage in rechargeable dead battery can be used which is a new concept adapted in this work. Though there are various methods for harnessing voltage piezoelectric materials are given high priority due to dual nature of converting mechanical vibration energy to electrical charge and vice-versa that is converting the electrical charge to mechanical energy.

Experimentation

Piezoelectric materials come under the category of solid materials which exhibits crystalline structured properties. In piezoelectric materials piezo means stress or pressure. Piezoelectric materials exhibit the property that under the application of mechanical stress or tensile force it generates electricity and thus vice versa. This particular feature of piezoelectric materials creates a new way of energy harnessing in eco-friendly manner by unwanted and wasted vibrations in vehicles because vibrations can be controlled but cannot eliminate completely. This work targets on these two points in which the piezoelectric circuit (Figure 1) has been fabricated and designed which consists of piezo electric coils are placed

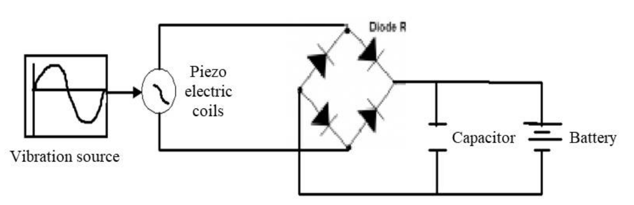

Figure 1: Piezoelectric circuit.

on thermocole sponges which are helpful to squeeze the piezo electric plates when the loads are applied on plates, rectifier, capacitor, boost converter, multimetre in series connection so as to harvest the voltage in rechargeable dead batteries. [5] proposes two methods of electrical power harvesting first one is using capacitor and later by using nickel metal hybrid battery and based on the pros and cons suggests the use of battery second one is better than first one that is capacitor this primary idea plays a key role for work that is the second method of power storage tested (Figure 2), to use rechargeable batteries, however, the concept of using piezoelectric materials to recharge a battery had not previously been shown. Therefore, tests were performed to demonstrate that the power output of a piezoelectric device is compatible with the battery. In this work using single method only considered in the form of simple circuit consists both capacitor and rechargeable lithium-ion dead battery in order to overcome the high discharge rate of capacitor allowing output as discontinuous signal.

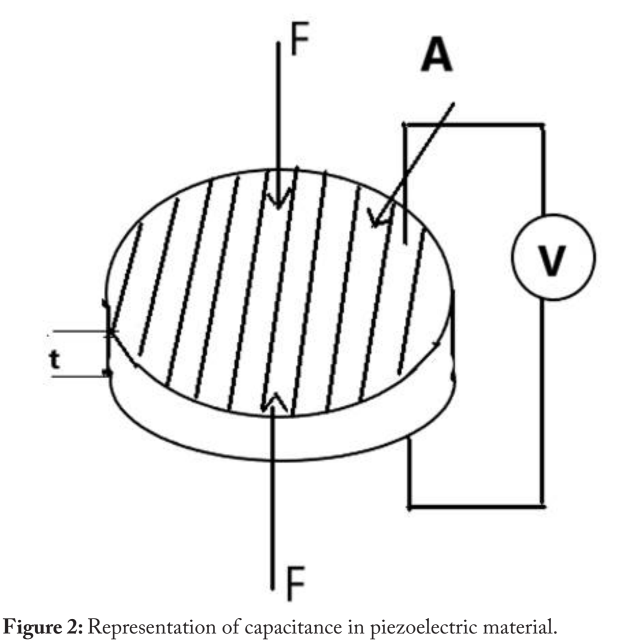

Figure 2: Representation of capacitance in piezoelectric material.

The above circuit was attached to the conventional bike and observed how the vibrations were captured and energy harnessing was carried out certain time period over the distance travelled and the same was performed by EV also. By selecting and checking the rear suspension system of a conventional and EV attached the piezoelectric coils of required dimensions in between suspension springs without any disturbance. The tools are used to loosen and tightening the suspension system of back axle. On the bottom of the piezoelectric disk, place the cardboard with thermocole sponges for support and squeeze piezoelectric plates and observe the vibrations in vehicle suspension system applied on piezoelectric plates.

Mechanical system

Assumed the 60% of net weight of the bike and the loads applied as follows. Glamour (BS6) Hero 124.7 cc, Design specifications: (W) =130 g, (w) = 123 kg, (W1) = 70 kg = 70 x 9.81 = 686.7 N, (W2) = 140 kg = 140 x 9.81 = 1373.4 N, spring type: coil spring, spring material: silicon alloy steel, n = 11. Assume 60% net weight of (bike + one person) = ((130 + 70) x 9.81) x 0.6 = 1177.2 N, T = 1177.2 N-m, N = 5000 rpm. Hero NYXe5 EV; Specifications: Lithium ion 51.2 V, 30 AH battery.

Electrical system with piezoelectric stack

Theoretically when the mechanical stress is applied on piezoelectric materials the effect is also due to electric polarization which will be similar in case of solid materials. The voltage V will be generated when capacitor is considered under the application of mechanical load on piezoelectric coils are connected in series for the two-wheeler suspension system.

Capacitance C of a capacitor used is 63V 33 μF and is represented by the relation C = ($€_0$ x A)/t. The 27 mm x 27mm x 0.16 mm piezo brass element (PZT ceramic), we considered in this has the properties as A = πr^2 = π x $(13.5)^2$ = 572; t = 0.16 mm, $€_0$ = 9.22 x 10^{-9} F/m; Q = D x F, d_{33} = 590 PC/N, F = 11265.8 N (F = m x a) t taken as assumption 60% net weight of (bike + one person). Acceleration for the bike as a = 9.57 m/s^2, Q = 1.44 x 10^{-5} Coulombs, V = Q/C, harvested voltage = (D x F x t)/($€_0$ x A) (Table 1).

Table 1: Voltage and harvested voltage using piezoelectric plates.

Voltage/No. of piezo plates	Voltage	Harvested voltage
Single piezoelectric plate	0.04 V	0.43 V
10 piezoelectric plates	0.4 V	4.38 V
20 piezoelectric plates	0.8 V	8.6 V

Results and Discussion

The above results were obtained when the both conventional and EV was attached to 10 piezoelectric colis only on the rear wheel of suspension system and observed that though we can harvest voltage but inorder to boost up we need minimum of 4 - 5 V, respectively. Later in the next case we considered 20 piezoelectric coils and observed as below.

By considering 20 piezoelectric coils attaching to the both sides of rear wheel suspension of Glamour bike, the harvested and boost up voltage over distance travelled in kilometre was observed and noticed that initially the voltage will be very low, the minimum voltage to boost up should be 4 - 5 V and the maximum voltage that can be stored depends up on the capacity of rechargeable dead battery and also noticed that after certain distance has been reached there is constant voltage that can be harvested means no further voltage can be harvested though we travelled for more distance (Figure 3 and figure 4).

By considering 20 piezoelectric coils attaching to the both sides of rear wheel suspension of Hero NyXe5, the harvested and boost up voltage over distance travelled in kilometre. Compared to the conventional bike the vibrations that can be harvested will be very low and the same phenomenon we observed in EV also as mentioned in case of conventional bike that after certain distance reached no voltage can be harvested further. The future scope of our project is to harvest the voltage continuously without any discontinuity in harvesting voltage (Figure 5 and figure 6).

Incorporating the nanomaterials in the design of piezoelectric materials at nano scale improves the efficiency, enhance performance of energy harvesting (Figure 7) for self-powered cells proposed a new fabrication of PVDF nano composite film-PZT (Table 2) uses a piezo separator using spin-coating synthesis method polarized for 30 min under 20 kV/mm

Figure 3: Graph plotted for conventional bike.

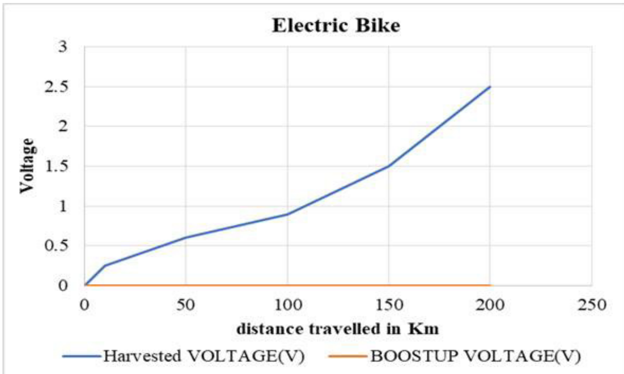

Figure 4: Graph plotted for EV.

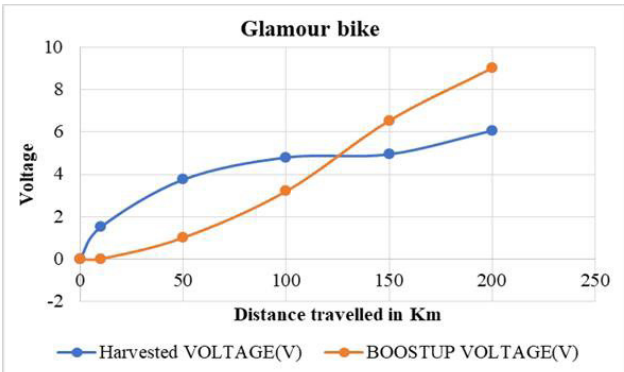

Figure 5: Graph plotted for conventional bike.

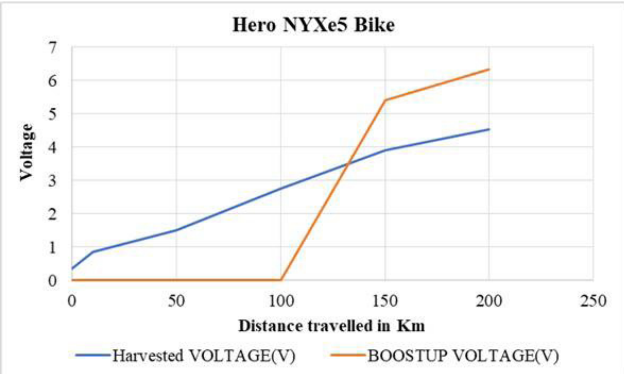

Figure 6: Graph plotted for EV.

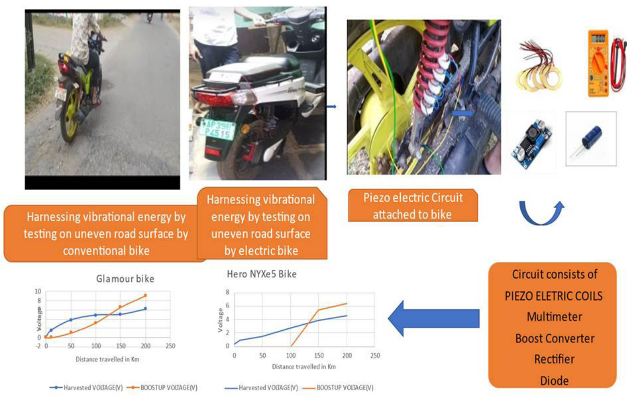

Figure 7: Harnessing of vibrational energy using conventional bike and EV.

Table 2: Comparison of PZT-ceramics to PVDF-PZT nanocomposite.

Materials	Compressive force (N)	Thickness (mm)	Voltage (V)	Piezoelectric constant (d33 PC/N)
PZT ceramics	1177.2	0.16	0.04	590
PVDF-PZT nanocomposite film	10	0.09	1.3	500 - 600

at 80 °C provides high piezoelectric output [33]. Comparing the obtained output voltage using PZT coils toPVDF-PZT nanocomposite film as follows (Figure 8 and figure 9).

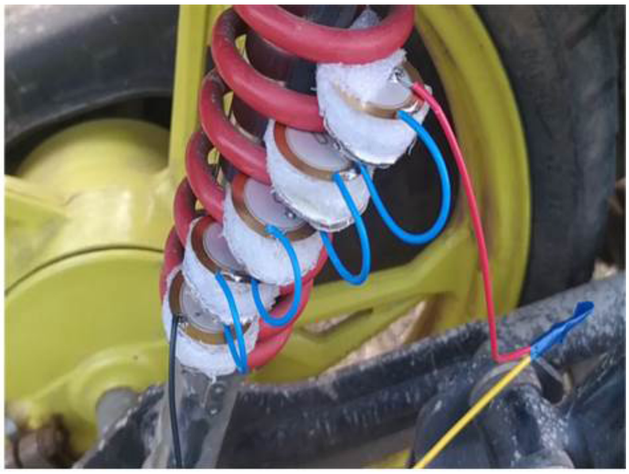

Figure 8: Circuit connected to conventional bike.

Figure 9: Circuit connected to conventional and EV.

Conclusion

The main objective of the work has been achieved by comparative studyof harnessed voltage through conventional and EV two-wheeler which was not done previously so far. To improve voltage, one needs to travel certain distance over the time period on uneven, rough roads than smoother ones. This proposed method of voltage harnessing from unwanted and wasted vibrations while travelling through a two-wheeleris simple, eco-friendlyas we increased the piezo coils the vibrations can be harvested better way. In this work the boost up voltage obtained from EV was low compared to conventional bike and the final output voltage was harvested in 6 V, 12 V rechargeable battery which is used to power low electronic devices as mobile charging, LED's, noticed that after certain distance has been reached there is constant voltage only can be harvested means no further voltage can be harvested though we travelled. By considering the PVDF-PZT nanocomposite film for 10 N of compressive force a voltage of 1.3 V can be harvested in self-powered cell which recommends the optimal solution for energy harvesting and the future scope of this work focuses on as coming era was full of EVs the vibrations were harvested eco-friendly and the boost up voltage can be used to charge the batteries in reserved condition where there is no conventional power stations to charge EV like remote locations, undersea, etc.

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Conflict of Interest

The authors declare no conflict of interest.

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