	Innovation Report Cover Page & Innovation Description Form **Human Powered Vehicle Challenge** **Competition Location: <u>Digital</u>** **Competition Date: <u>3rd April, 2021</u>**
This required document for <u>all</u> teams is to be incorporated into your Innovation Report. ***<u>Please Observe Your Due Dates</u>; see the ASME HPVC website and rules for due dates.***	

University name: National Institute of Technology Silchar

Vehicle number: 17

Innovation Title: Piezoelectric Energy Conversion, Storage and Distribution System.

Innovation summary:
A non-conventional energy conversion, storage and distribution system based on the piezoelectric effect using PZT (lead zirconate titanate) in areas where impacts of loads and forces are realized. Basically, a piezoelectric energy harvesting using various loads and forces in standard bicycle or HPV (Human Powered Vehicle).

INNOVATION REPORT 2021

TEJAS 6.0

(VEHICLE NUMBER – 17)

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1. DESIGN

A) New Idea-

Innovation is the creation, development, and implementation of a new idea to improve efficiency, effectiveness, or competitive advantage. Our proposed innovation is designed keeping in view all these important factors. In the case of HPV (human-powered vehicles), various kinds of mechanical loads and forces generally act at different positions of the vehicle. Most of these loads can be useful and can be converted into the electrical form of energy. This is the main idea behind our innovation. At this initial stage of the innovation, we are mainly focusing on the **braking and suspension** areas of the vehicle but with proper research work, the idea can be extended to different parts of the vehicle. For conversion of the mechanical to the electrical form of energy, we propose the use of **piezoelectric** material. This is a special material that produces electrical potential if stress is being applied to it and vice versa. Piezoelectric materials are available in both natural and artificial forms. Thus, in brief if the various stresses acting on the different parts of the vehicle are made to act on piezoelectric material, then an electric potential output can be produced which can be stored in a rechargeable battery and in turn, this energy from the battery can be used to run a dc motor whenever necessary. Innovation is also developed to fulfil various needs and to solve important problems. This innovation can have a good impact on the efficiency of the vehicle and whenever the rider of the vehicle is in the need of some instant power output this innovation can come in handy. The feasibility of our idea is explained in detail in this report but in brief, the availability of the material and flexibility in the fabrication of the material has been accomplished in previous efforts to harvest energy from piezoelectric material which ensures the feasibility of our idea. Although, our innovation or idea is inspired and motivated from previous works done in the field of piezoelectric energy harvesting but in no manner, it is the imitation of the below mentioned patents and research papers. which are as follows-

1) Footstep Voltage Generator using Piezo-Electric Transducers
2) Piezoelectric Energy Generation from Vehicle Traffic with Techno Economic Analysis
3) Piezoelectric energy harvesting pedal integrated with a compliant load amplifier

B) Need-

These days, due to heavy dependence on fossil fuels and other sources of non-renewable energy, there has been a high demand for alternative sources of power for vehicles. Human power is the most economical when it comes to vehicles in small-scale industries. But due to the heavy workload environment, one cannot solely rely on human power alone, which otherwise makes workers prone to unhealthy conditions.

Therefore, the Piezoelectricity charged Human Powered Vehicle (HPV) serves to reduce the human effort by assisting the rider with the help of a motor powered by a battery which is charged by piezoelectricity. It serves as the cost-effective alternative (operating cost) to conventional motorbikes and mopeds for both domestic and commercial uses viz. Delivery and courier services, as the increased load adds to the amount of electricity generated in the form of piezoelectricity, is very effective in harnessing the excess human efforts, braking energy and energy of load into electrical energy thus minimizing the wasted energy.

C) Advancing the Art of HPVs-

The benefits of innovation are the key features that help us in realizing its potential. Our proposed innovation has quite a lot of benefits that it can offer. The main benefits of the innovation are as follows-

- **Reduction in the human effort-**

  In different circumstances the needs of the human efforts are different. In some cases, the need is much more than an average human can deliver for a long period. Thus, this innovation ensures that in this kind of situation the rider can have continuous help in riding the vehicle through the power generated by the piezoelectric plates.

- **Independent of conventional energy sources-**

  A lot of conventional energy resources are non-renewable and at worst the fossil fuels are environmentally degrading. Our innovation on the other hand does not depend on any of the conventional energy resources rather it is a new way to harness the benefits of piezoelectric material.

- **Electrical energy gained through human and loads:**

  While riding a bike, the pressure is exerted, minute and significant, across different body parts which can be utilized for energy generation. So, why not use piezoelectric technology to assist our riders? Using this technology, we can convert pressure exerted on desired areas from human & extra loads into electrical energy which further is used to power the motor. This will increase riding time while reducing human effort.

D) Technology and Concept Feasibility Study-

The feasibility of an idea is often related to many factors such as scientific principles based on which the innovation will work, plan of action of the idea, material availability, and fabrication, previous works in the particular field of innovation. Below we have described these important factors in detail.

- ### Scientific principle-

Our proposed innovation is based on the piezoelectric effect. According to the definition of the piezoelectric effect electric charge accumulation occurs due to applied mechanical force or stress. This phenomenon mainly occurs in the case of non-centrosymmetric crystal structures. The piezoelectric effect can be divided into two parts called –

1) Direct piezoelectric effect
2) Converse piezoelectric effect

In the case of the direct piezoelectric effect application of mechanical stress in a piezoelectric material can generate an electric field. While the generation of deformation in a material due to the applied electric field is called the converse piezoelectric effect. Both of these phenomena can be described by the following equations-

$$D = dT + \varepsilon E \ldots. (1)$$
$$S = sT + dE \ldots. (2)$$

where S is the strain, T is the stress, E is the electric field intensity, D is the electric displacement, d is the piezoelectric coefficient, " is the permittivity, and S is the elastic compliance.

In our idea, we are using the effect of the direct piezoelectric effect. Thus, according to equation (1) the application of higher stress can generate more electric displacement. But the power or voltage output depends also on the thickness of the material.

■ **Availability of Piezoelectric Materials-**

There are around 200 piezoelectric materials used in energy harvesting applications, found in four main categories:

• Single crystals (Rochelle salt, lithium niobate, quartz crystals);

• Ceramics (barium titanate ($BaTiO_3$), lead-zirconate-titanate (PZT), potassium niobate ($KNbO_3$));

• Polymers (polylactic acid (PLA), polyvinylidene fluoride (PVDF), co-polymers, cellulose and derivatives);

• Polymer composites or nanocomposites (polyvinylidene fluoride-zinc oxide (PVDF-ZnO)), cellulose

BaTiO3, polyimides-PZT

Another classification of piezoelectric materials is:

• Naturally occurring: Quartz, Rochelle salt, Topaz, Tourmaline group;

• Synthetic: Barium titanate, lead titanate, lithium niobate, lead zirconate titanate.

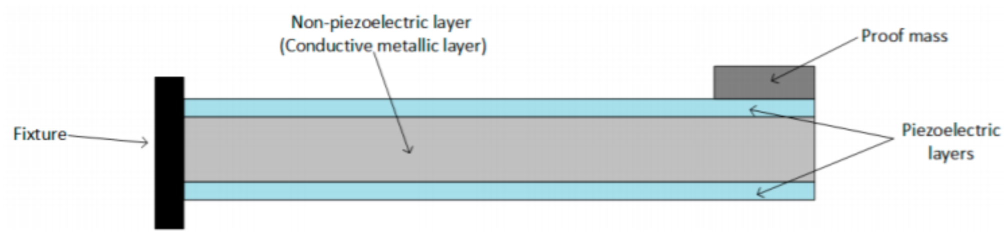
The choice of a piezoelectric material depends not only on their piezoelectric properties and the functionality of the application sector but also on parameters such as design flexibility, application frequency, and available volume.

The most commonly used materials for piezoelectric energy harvesting devices used to be lead-based materials such as PZT (lead zirconate titanate). Hence the same is used in our design. Lead zirconate titanate (PZT) is the most popular piezoelectric ceramic material. The popularity of PZT is due to the fact that it is one of the most efficient and cost-acceptable materials. Due to concerns regarding the presence of lead in PZT, it demands a call for lead-free alternatives such as BaTiO3. But on the downside, these lead-free alternatives are not that much easily available and the transduction efficiency is quite low as compared to that of PZT. Piezoelectric polymers could have been a better candidate for piezoelectric energy harvesting applications since they are mechanically flexible, so they can withstand high strain. But a huge disadvantage using them is that the material is not quite as cost effective and easily available as PZT. So PZT is used for the design.

Types of Transducers

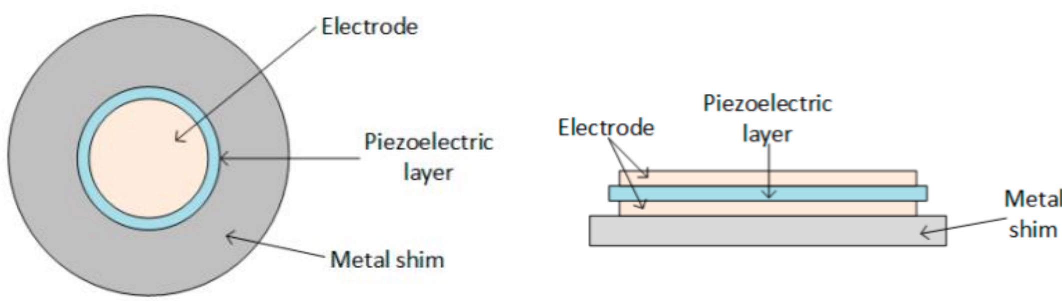
- Cantilever beam
- Circular diaphragm
- Cymbal type
- Stack type

- Cantilever Beam



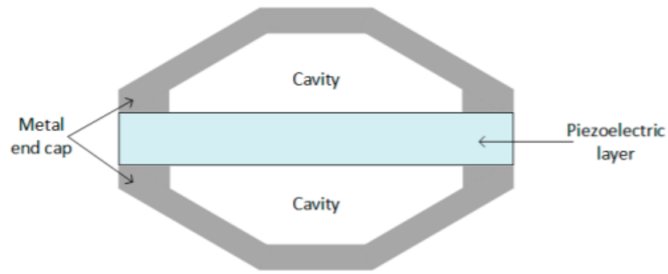
The cantilever beam structure consists of a thin piezoelectric layer (or two layers) and a non-piezoelectric layer (usually a conductive metallic layer) fixed at one end to achieve a structure operating in its flexural mode and is the most widely used due to its simple geometry and generation of the maximum amount of strain.

- Circular Diaphragm



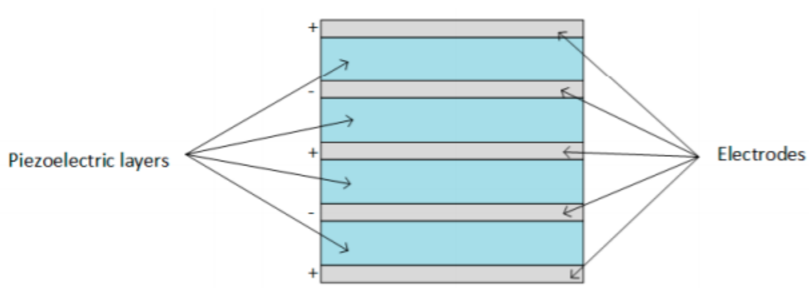
The circular diaphragm structure consists of a thin disk-shaped piezoelectric layer attached to a metal shim fixed on the edges of the clamping ring. At the core of the diaphragm is attached a proof mass to intensify the performance under low-frequency operation and to improve the power output.

- Cymbal Type



Cymbal transducers consist of a piezoelectric layer placed between two metal end caps on both sides, and they are useful in applications with higher impact forces. Applying axial stress on the metal end caps, the stress is amplified and converted into radial stress, which leads to a higher piezoelectric coefficient and, therefore, higher charge generation from the piezoelectric energy harvester.

- Stack Type



Stack piezoelectric transducers consist of multiple piezoelectric layers stacked over each other in a way that the poling direction of the layers aligns with the applied force and are used in applications which demand high pressure.

In this design, we have used two types of transducers, namely the circular diaphragm and the stack type. the circular diaphragm is used in the rear suspension as it is round and accommodated accordingly in the circular section. Whereas the stack type was used in pedals and brakes as they involve a lot of pressure application. With this high pressure, high voltage output is obtained.

Description of the innovation-

As stated earlier in the introduction part our idea mainly focuses on utilizing loads on various parts of the HPV. below we have described the main areas of our interest where we are extending our idea as follows-

- **Braking-** A very big part of the forces or loads in the HPV is concentrated in the braking area. There are mainly two types of brakes used in bicycles or HPV-
  a) Rim brakes and b) Disc brakes. As for performance, the disc brakes are preferred over the rim brakes because of the ease of braking and the high impact it offers in the centre of the wheel. In our case also we prefer the disc brakes instead of the rim brakes because of the usefulness of their high impact. Disc brakes are also weather friendly and it reduces the wear and tear of the bicycle wheels as it does not press against the wheel's outer periphery. Disc brakes are further classified into mechanical and hydraulic types. Again, due to the ease of braking and high impact the hydraulic type is preferred. Hydraulic discs feature a closed system of hoses and reservoirs containing special hydraulic fluid to operate the brakes. When the lever is activated, a plunger pushes the fluid through the hoses and into the calliper where the pads are pushed onto the rotor, stopping the bike.

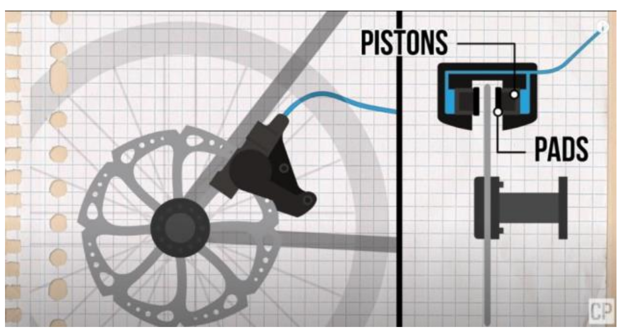


Fig: Standard disc brake assembly.

As seen from the image below we intend to use the braking forces of the pads. For that, we will insert a layer of piezoelectric transducer specifically PZT (lead zirconate titanate) embedded in the pads of the disc brake. Thus, when the brakes are applied voltage output will be produced at the terminals of the PZT transducer which can be stored in a rechargeable battery.

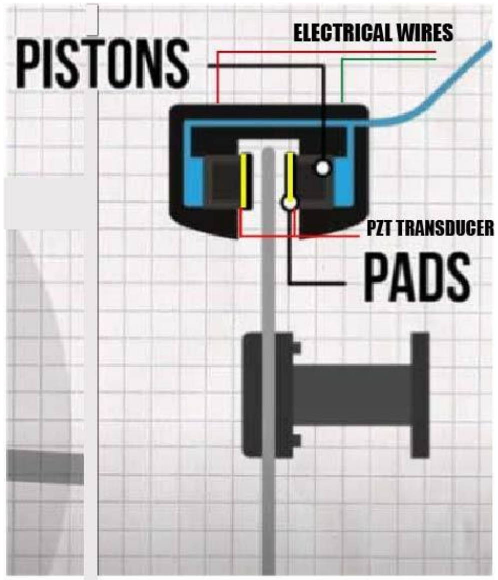


Fig: schematic diagram of PZT in break.

Regarding the shape of the PZT transducer use of a stacked type structure is preferred as it can withstand high impact forces.

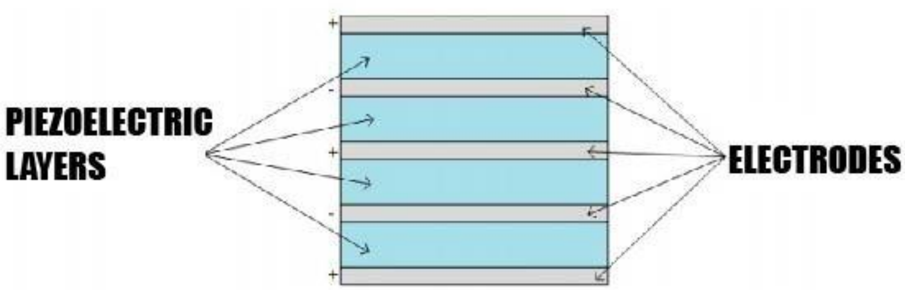


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Fig: Stack Type Piezoelectric Transducer

- **Suspension**- In order to achieve comfort in riding HPVs, especially in rough terrains, front and rear suspension systems are used. These systems are designed to reduce the shocks and jolts experienced while riding. The suspension system includes a damper for shock absorption and spring for rebounding.

  In this design our aim is to harness the energy which is available in the form of shocks and jolts in the form of electrical energy, thus making this innovation more and more energy efficient.

As seen in the diagram, we insert layers of piezoelectric transducers, PZT, the same material as we used in brakes. This is concentrated at the two ends of the shocks

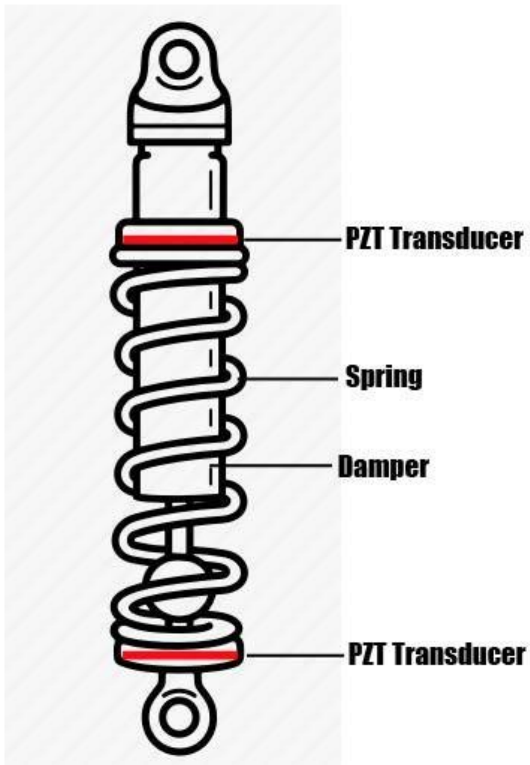

Fig: schematic diagram of PZT in suspension.

Absorbers in the form of concentric rings unlike that of the brakes, where the vehicle experiences the jerks and shocks. The voltage output is produced at the terminals of the PZT transducer which can be stored in a rechargeable battery.

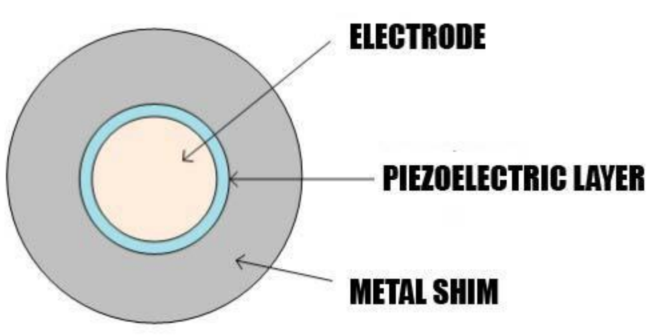

Fig: Circular diaphragm type PZT transducer.

- **Pedal:** To propel a bicycle a rider has to push the pedal with their foot. A pedal usually consists of a spindle that threads into the end of the crank arm, and a body on which the foot rest is attached, that is free to rotate on bearings with respect to the spindle. While riding a bicycle, continuous force is required to push the pedal. From this good amount of voltage can be produced using a piezoelectric transducer. For this voltage to be stored in a battery we will need a PZT transducer, Printed Circuit Board (PCB), 4 plates, connecting wires.

  We will fix the PZT transducer in the pedal whose two output terminals are connected with plate 1. Now plate 1 is connected with plate 2 which is further connected with one end of PCB. Other end of PCB is connected with plate 3 which is further connected with plate 4. Now wires from plate 4 are connected to the amplifier whose connection is with the charge controller and battery for storing the produced energy. So, whenever a rider rides a bicycle, pressure is exerted on the PZT transducer. The voltage which is produced in the PZT transducer is transferred to the battery using provided connection.
  Below is a diagram to understand the working more conveniently.

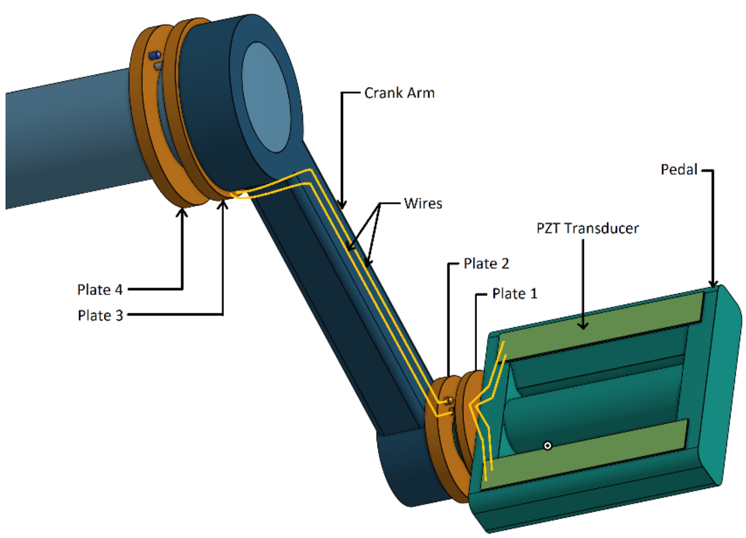

Fig.: Schematic Diagram of PZT in pedal.

Here, plate 1 is fastened with pedal while plate 2 is fastened with crank arm. Whenever the pedal is rotated both the plates will rotate with respect to each other in such a way that they will be connected and complete the circuit.

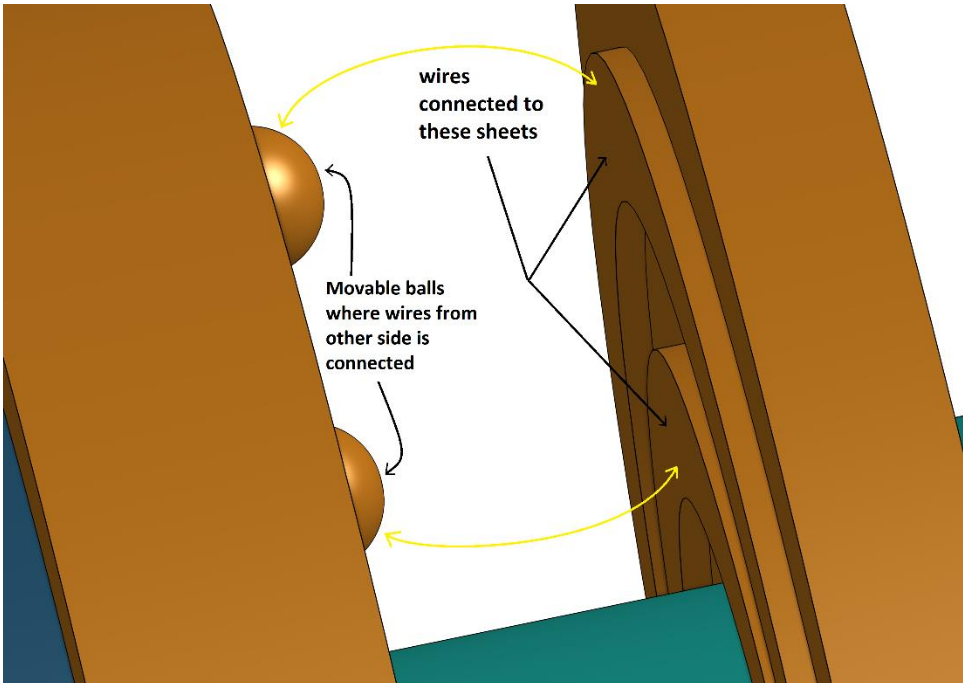

Fig.: representation of connection between two plates.

Circuit connection- As mentioned earlier there are three main areas of the bicycle from which voltage is being produced which are- the disc brakes, rear suspension and the pedals. As we can see in the image below from each of these units the electrical wires are carried along the body of the bicycle and all of them are then connected to the amplifier for amplifying the net voltage output. The wirings are wrapped along the bicycle with a rubber based light material sheet for protection from outside environment and other possible damages. From the amplifier the connection is done with the charge controller and from the controller to the rechargeable battery (24v, 10ah). The battery is then connected to the dc motor (24v, 250w) with a switch to control the motor. The controller is used to protect the battery from overcharging. A switch is connected between the motor and the battery situated at the handle to provide control to the motor.

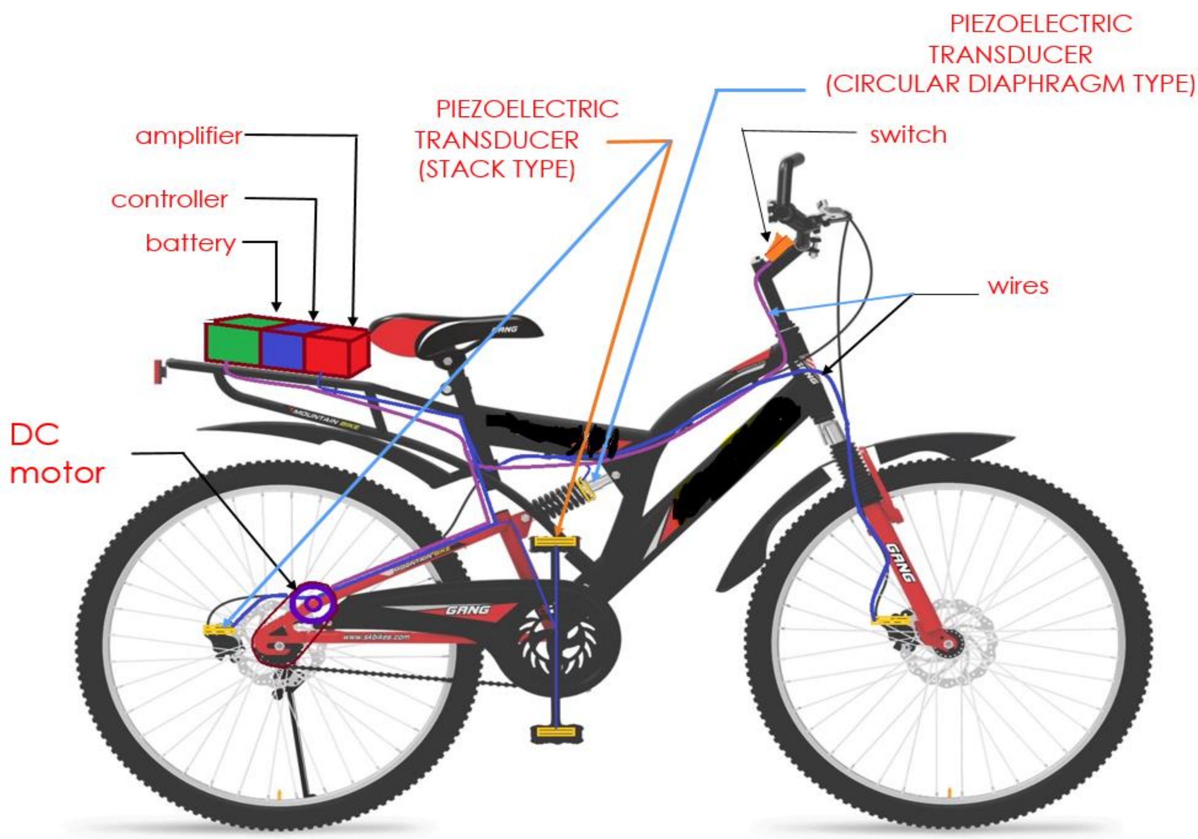

Fig.: Representative Diagram of The Innovation.

2. CONCEPT EVALUATION:

A) Funtionality Evaluation-

Due to the current situation of Covid-19, there was no physical meeting of the members, which has affected the smooth flow of ideas and their implementation and access to the workshops and labs in college. The production of the physical prototype of the design was not possible. However, we have represented our analysis and calculation on individual parts separately.

B) Benefit Study-

The data's used here are not experimental due to lack of prototype thus estimated data's (based on practical average values) for various parameters are used.

- **Braking (For one wheel)**:
  Force = 700N
  Area of Plate = $20 \times 15\ mm^2$
  Thickness of Plate = 2 mm
  Number of Plates = 2

- **Suspension(rear)**:
  Force = 300 N
  Area of the Plate= $\pi \times (11mm)^2$
  Number of Plates = 4

- **Pedal**:
  Force = 700N
  Area of one Plate = $7.2 \times 10^{-4}\ m^2$
  Number of plates = 4 (effective plate=2)
  Thickness of Plate= 3 mm

■ **Voltage from each of the unit**:

Here the piezoelectric constant, g=$10 \times 10^{-3} \frac{Vm}{N}$

- **From Brake:**

The voltage output without amplifying can be calculated from the formula:

V=$g \times h \times \left(\frac{f}{A}\right)$

Here,
f= 700N,
Area, A=$20x15mm^2 = 300x10^{-6}m^2$
g=$10x10^{-3}\,Vm/N$
h= 2mm
No. of Plates= 2
Hence,
V=$\frac{10\times10^{-3}\times2\times10^{-3}\times700}{300\times10^{-6}\times2}$
V= 23V.

Similarly,

- **From Suspension:**

The voltage output without amplifying can be calculated from the formula:
V=$g \times h \times \left(\frac{f}{A}\right)$
here,
f= 300N
A= $\pi \times (11mm)^2 = 380mm^2 = 380 \times 10^{-6}m^2$
h = 2mm
No. Of Plates = 3
V= $\frac{10\times10^{-3}2\times10^{-3}\times300}{380\times10^{-6}\times3}$
V= $\frac{15.78}{4}$
V= 3.94 V

Now,

- **<u>From pedal:</u>**

The voltage output without amplifying can be calculated from the formula:
V=$g \times h \times \left(\frac{f}{A}\right)$
here,
f= 700N
g= $10 \times 10^{-3}\,Vm/N$
h= 3mm
A= $7.2 \times 10^{-4}m^2$
No. Of plate= 4 (effective plate=2)

V= $\frac{10\times10^{-3}\times3\times10^{-3}\times700}{2\times7.2\times10^{-4}}$
V= 14.58 V

These calculations are based on assumptions and due to various frictional forces, the voltages can be much lower and thus they are connected in parallel and using the amplifier we can get the suitable voltage to run the DC motor.

C) Unanticipated Benefits-

The power which is generated with the help of the piezoelectric transducers from braking, pedals and rear suspension is only used to run the dc motor at times of need by the rider. But it can also be channelized in a way to run electronics set up which can not only improve the bicycle's performance but can be useful for other aspects of the bicycle.
Large amount of voltage is also generated so other than motor power other electronic circuits can also be operated simultaneously.

3. LEARNINGS:

A) Failures:

Despite having advantages like efficient exploitation of waste mechanical energy and ability to transform to convenient shapes, the piezoelectric transducers come with the following downsides -

- **Low voltage output**-The signal produced is so small that it compulsorily requires the use of an amplifier.

- **Temperature effects**-On top of that the increase in temperature has an adverse effect on the output voltage (decrease with the increase in temperature).

- **Space optimization problems-**Furthermore, there were a lot of concerns and uncertainty about the structural integrity of the piezoelectric material, hence it couldn't be applied to harness energy from many parts of the vehicle (Front suspension in our case).

  In order to achieve maximum utility of this innovation, we must minimize these effects in our design.

B) Learning From Failures:

The above-mentioned failures were analysed and we came up with some alternate solutions to these which are described as follows-

- In concern with the low voltage output along with the use of amplifiers, instead of using single plates PZT transducers we used multiple number of PZT transducers in an effective series and parallel combination for better output voltage production.

- The alternative of the front suspension we found are the pedals. With an innovative design for the pedals, we tried incorporating the PZT transducers in pedals where a significant amount of load is applied by the rider’s feet.

C) Negative Aspects of the Design-

- **Idea optimisation for using of PZT in pedal:**
  The idea of producing energy and storing it in a battery is easy to represent but fitting the PZT and connecting the wires while maintaining the standard space is difficult. Fitting the PZT in the pedal modifies the original pedal to a great extent. Also, connection using plates and PCB is not much efficient as compared to normal wire connection as in this connection some parts are not permanently joined and are always in motion which may wear the parts. This makes the structure a little clumsy and complex.

- **Complicated circuit design and assembly-** Our design consists of three main parts in the vehicle where we are utilizing the loads which are- disc brakes, pedals and rear suspension. Considering all the three areas and the distance between them, the design of the assembly to harvest the energy is a challenging aspect as it is a bulky assembly and can increase the weight of the bicycle by some amount which can affect the overall performance. One more negative aspect is that the construction of the circuit keeping in view the ergonomics, space and different motions in the bicycle is also quite complicated.

4. EXECUTION-

A. Concept Functionality Based on Quality of Design:

Experimentation was done individually on separate parts as the analysis on the prototype as a whole could not be done. Thus, we have to make conclusions based on the individual parts. From the calculations done the idea is working satisfactorily according to the needs stated. We are very sure if further experimentation is done on this concept, we can turn it into reality.

B. Quality of Execution in Strengthening the Benefits of Innovation:

From the estimated data (practically possible) the voltage that was gained from the PZT transducers without amplifying and after amplifying the voltage, theoretically it can be seen that we can use this voltage to run DC motor (up to 24 volts) and other electronic setups (like Arduino, Bluetooth sensors, etc).

5. CONCLUSION-

This innovation was designed keeping in mind the ASME Design Requirements.
From the report we can say that this innovation not only advances the state of the art in human powered vehicles but also provided the team with an opportunity to demonstrate the technical skills.
We have developed the idea of harnessing power from various parts of a bicycle like brake, suspensions and pedals using piezoelectric transducers. Using this idea, an adequate amount of energy can be generated and be put into use for motor assisted cycling.
This idea indeed resorts to harness the excess human and load vibration energy, thus amounting to efficient management of energy. Since its source is independent of conventional sources of energy like fossil fuel, it is a very clean source of energy.
During the development of design, there were various situations which required creativity, brainstorming and coordination among teammates, where we put our technical skills, communication skills and also leadership skills on test. This was indeed a fruitful experience.
Due to the high difficulty of the innovation (particularly involving regenerative braking), it wasn't possible to create a physical prototype. Hence analysis on individual parts was done. The test results on individual parts were satisfactory and it is highly likely that with further experimentation and research to develop a real-life model, this concept would be put into use in real life.

6. REFERENCES-

Below is the list of references and citation used in the innovation report:

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