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Research Experiences for Teachers and Young Scholars in Advanced Self-Powered Systems of Integrated Sensors and Technologies (ASSIST)

SSIST | NSF

Application of a Mechanical Energy Harvester for Feedback on Cyclists' Downstroke Forces

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Problem

Average Life Expectancy for a person born in the United States *declined* for the first time since 1993.

In 2014 **23% of deaths were related to heart disease**

Heart disease costs the United States $207 Billon Annually, in treatment, medication, and lost time.

The United States Surgeon General recommends 2 hours and 30 minutes of moderate-intensity exercise per week to minimize likelihood of heart disease.

Response

Provide simple "coaching" that allows for both novice and experienced cyclists to ride with appropriate technique, increasing likelihood of regular exercise and positive responses in health.

Engineered Solution

A battery-less sensor that detects biomechanics pedal downstroke force and can be analyzed for lateral balance detection. The sensors, installed in the cyclist shoes or pedal cleat, uses a bulk ceramic to produce a voltage that varies in response to foot-to-pedal force.

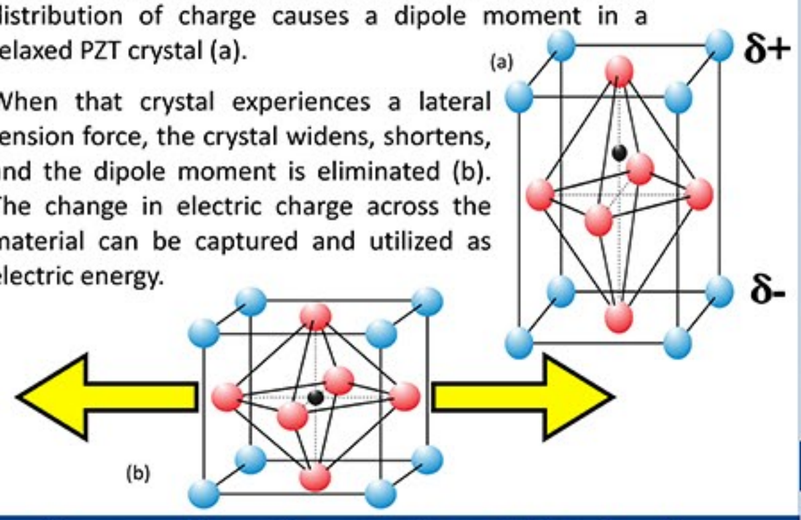
<u>Application Constraints</u>

- must be designed small enough to remain comfortable for the user — no noticeable increase in pedal load or foot weight
- must be able to withstand forces of magnitudes greater than users' body weights
- materials must be affordable
- must not rely on external power supply

Harvesting Mechanical Energy Using PZT

Piezoelectricity in materials results from the asymmetry of ions throughout a crystalline material. This uneven distribution of charge causes a dipole moment in a relaxed PZT crystal (a).

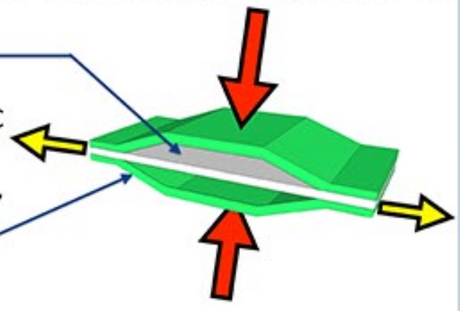
When that crystal experiences a lateral tension force, the crystal widens, shortens, and the dipole moment is eliminated (b). The change in electric charge across the material can be captured and utilized as electric energy.

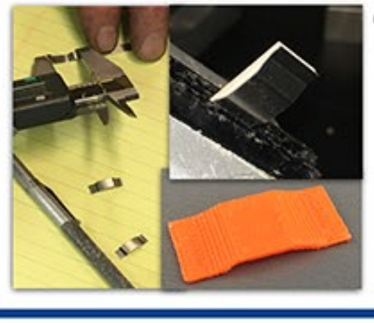


Sensor Development and Production

Modified cymbal transducer (flextensional) will convert a vertical compression into a lateral stress when endcaps are fastened to the piezoelectric material

- Ceramic PZT
  - vertically poled
  - provided by APC International, Ltd.
  - Navy II (Type 850), silver electrode
- Metal or ABS endcaps
  - Modeled in SketchUp
  - Produced in two sizes
    - 20.00 mm x 9.50 mm x 1.50 mm (in footbed of shoe)
    - 15.00 mm x 5.00 mm x 0.50 mm (in cleat)



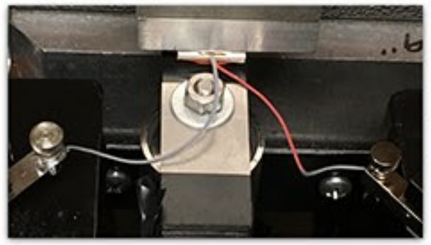


Metal endcaps were pressed using a die in brass and and steel

ABS endcaps were 3D printed on a Makerbot Replicator (5th Gen.)

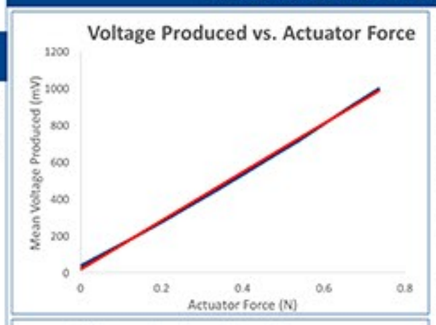
Sensor Experimentation

Four sensors were categorized and tested as follows: Small steel, large steel, large brass, and large ABS. The sensors were placed securely between a rigid metal stop and a piezoelectric stack actuator. A lock-in amplifier was used to generate a AC sine wave that drove the actuator at a variety of frequencies. This wave caused vertical compression of the sensor between the actuator and the metal stop, and electrodes were used to measure the voltage of the resulting signal produced by the sensor.

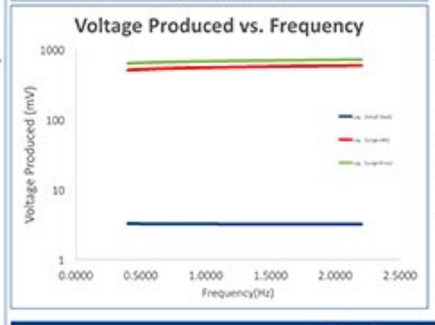


The signal voltage was collected and analyzed using a lock-in amplifier, and evaluated as a function of compressive force and the frequency of actuation.

Evaluation and Analysis



All sensors tested produced a regular voltage that was directly related to the force that the sensor experienced. In Addition, the electric potentials in all sensors were greater than anticipated, and out of the range of the lock-in in the case of the large steel sensor (over 1.0 V).



All sensors produced a reliable signal with little variation of voltage as a function of frequency when tested through likely range for cycling (0.5 Hz - 2.4 Hz). This shows that the sensor can be used for slow cadence leisure riding as well as high cadence training.

Future Work

The next step in the development of this device is establishing connectivity between it and and micro-controller for real-time analysis of pedal mechanics. This will allow for feedback to be delivered to the rider when an imbalance in downstroke force exists between the left and right feet. In addition, the finished device should be contained by a rigid waterproof membrane to provide a buffer from high forces and environmental elements.

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