Research & Development of Triboelectric Energy Generation for Military Applications

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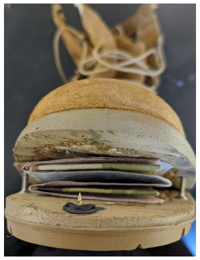
Abstract

In collaboration with the U.S. Army Combat Capabilities Development Command (DEVCOM), this MQP team aimed to modify equipment worn by a soldier to be capable of providing power to external electronic components. Our prototype designs implemented triboelectric nanogenerators (TENGs) into the military footwear to capitalize on unused energy generated when walking. TENGs behave based on the triboelectric effect, which produces electrical power through the dynamic interaction of two triboelectric materials. Multiple areas of focus in this project were consolidated to produce an optimized final prototype. Researched rectification circuits were printed onto flexible substrates to output a linearized direct current from TENG input. An automated tester was constructed to provide consistent force for testing. Separate TENG iterations were constructed and tested to analyze the effect of spacing and surface contact between triboelectric materials. These areas of research and development allowed our team to improve prototypes and design our final prototype.

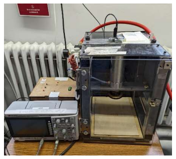
Objectives

- •Design an automated tester capable of evaluating TENGs performance relative to walking.
- •Design and test circuits capable of rectifying current inputs similar to that of a TENG and supplying power to external devices.
- •Design and evaluate iteration of the TENG design to increase voltage output.
- •Develop separate prototypes modified for different locations in footwear.
- •Construct a final design that optimizes results from the previous testing.



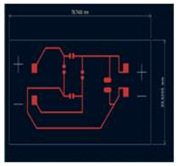
Automated Tester

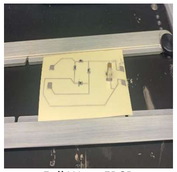
- •Designed to simulate the force of rucking
- •Based on soldier weight and walking mechanisms
- •Uses a pneumatic cylinder on steel
- •Electronic controller allows safety features and changeability

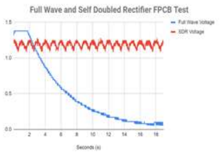


Rectification Circuit Design & Testing

- •Six rectification circuits were researched and simulated utilizing Multisim
- •Four circuits were then constructed on breadboards and evaluated
- •The top two performing circuits' designs were then densified for flexible printed circuit board (FPCB) fabrication
- •A Voltera V-One printer was used to dispense the two rectification circuits onto a PET substrate

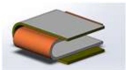

Full Wave KiCAD Design

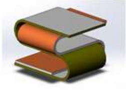

Full Wave FPCB



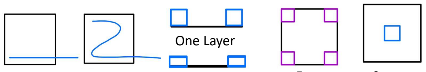
TENG Iterations

- •Designed twelve separate iterations to be tested on 2"x2" insert of automated tester
- •Iterations changed surface area contact and gap between layers
- •Data was analyzed to find the average peak-to-peak voltage for each iteration
- •Folding three times performed the best with an average of 0.561V

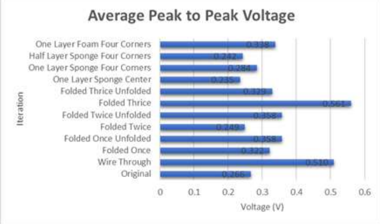

Once Folded


Double Folded


Triple Folded

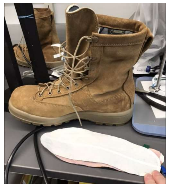


Original
Wire Through
Half Layer
Four Corners
Center Sponge



Prototype Stage One

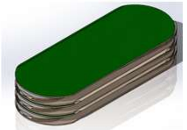

Midsole I


Insole I


Sock I


Sock-Insole I

Prototype Stage Two


CAD TENG Prototype

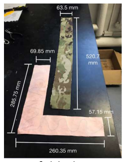

Insole II


Midsole II

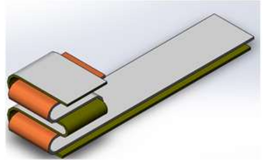
Prototype Stage Three

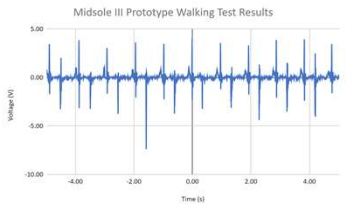
Key Features:
- •Hybrid TENG fold pattern implemented within prototype
- •Fold placed toward ball of foot
- •Adhered TENG to boot to increase space between positive and negative triboelectric materials
- •Midsole layers secured with screws


Boot with TENG


Unfolded TENG


Screw Locations


CAD Final TENG Design



Recommendations

- •Incorporate mechanical components to aid in the separation between triboelectric material layers
- •Evaluate the current output of prototypes to better understand their power supply
- •Cast or print rubber for the sole of the shoe to better implement a TENG with minimal changes made to the original structure of the boot
- •Perform more material quality tests on TENG iterations (fatigue, bending, compression, endurance limits, resilience)
- •Implement circuit components within rectification circuits to minimize unwanted noise and abnormal current flow

Conclusions

The completion of this project marked a critical improvement in the development of a TENG system capable of being worn by a soldier on active duty. Though the rectification circuits were not able to output a power supply suitable for an external device, we believe devices such as transistors and other current modifying components can be implemented in order to produce the desired power outputs. The design and testing of twelve separate TENG iterations can be used to better understand the nature of TENGs and their potential applications. We are confident the Midsole III prototype can be further optimized through the continuation of this project. With proper subsystems integrated and interfaced correctly, this designed prototype would present itself as a reliable system to be utilized within missions.

Approved for Public Release