Evaluating the Efficiency of Affordable Piezoelectric Shoes for Low-Power Device Charging

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Abstract - *In this day and age, it is essential to look for more ways of generating renewable energy without hampering the environment. However, it is also important to understand the efficiency of such new technologies. One such technology is the concept of piezoelectricity and how it can be used to generate electricity to charge our everyday essential devices like phones and watches.*

This paper deals with one such type of new idea that has been thought of many times previously but has never been implemented properly. That is a shoe that can generate electricity by walking. It uses piezoelectric discs of 27mm diameter which are placed in strategic locations of the shoe for maximum energy output which will be discussed later in this paper.

Key Words: **Piezoelectricity, Renewable Energy, Efficiency of electricity generation, Electric Shoe**

1.INTRODUCTION

Piezoelectricity is a principle that talks about electricity generation by applying mechanical stress/force to a piezoelectric crystal in order to generate electricity. It is a simple yet an effective principle to make various innovations useful for the public and governments to generate cost effective energy to power low energy equipment by installing piezoelectric devices.

The concept of electricity-generating shoes has been thought of many times but has rarely been implemented. However, even in these implementations, the prototypes are often made with such high cost of production that these are not likely to be affordable to the mass middle-class public, especially in regard to India.

We have come up with a shoe that requires minimal costs to make the shoe affordable for the larger masses. Even though it might be far from mass production, it is implemented by us and thoroughly tested and experimented, of which the conclusions we have taken to make this research paper.

This shoe was originally made for a competition called Ideation Express conducted by the E-cell of IIT Madras in 2024. Subsequently, we have named the shoe," PowerKick". Even though we didn't acquire a proper winning position in the competition, we think that a special mention by the judges is really something to motivate us to work on this further.

Thus by experimenting thoroughly, we have come up with the conclusions of the efficiency of such electricity-producing shoes and we have noted the conclusions down in this paper.

1.1 The Working of piezoelectricity in relevance to this project:

The piezoelectric disc used in this project works on the principle that the quartz or ceramic material it is made up of, produces an electric current upon mechanical stress.

The quartz disc is made up of silicon and oxygen combined with bonds.

Oxygen is more electronegative than silicon. Due to this, the bond present between silicon and oxygen is polar.

In its hexagonal structure, the net electric charge is at the centre of the structure. However, due to mechanical stress, it changes position. This change in position leads to the creation of voltage.

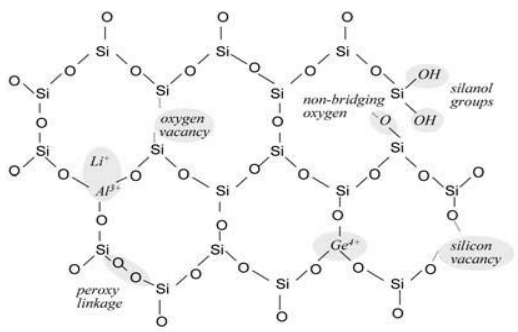


Fig 1. Structure of Piezo electric Quartz

2. The Electricity Producing Shoe (PowerKick)

2.1 Foundation:

The base of the whole setup is a hard material like ABS Plastic. Lets call this the Base for future reference. The Base is cut out in the shape of the heel of the shoe where the piezoelectric discs that generate electricity have also been placed as the heel is the part of the foot that experiences maximum pressure. (Note: The shoe size is taken 8 UK for this project).

2.2 Piezoelectric Components:

There are 6 total piezoelectric discs of 27 mm diameter and max 4 V potential difference used.
The term disc/discs has been used to refer to piezoelectric discs.

Three discs have been placed in a triangle formation on top of the base. The discs are placed very closely together although not in contact. They are connected by thin wires in parallel for optimum Voltage. The resistance offered by the wires in negligible for this project. This configuration will now be called C1 in this paper.

The same configuration has also been done on the underside of the Base with the other three discs. This underside will be represented by C2 now.

The discs in C1 and C2 are connected to its own individual bridge rectifiers that are connected in parallel to each other. These bridge rectifiers are to stop the backward flow of current and convert AC to DC. The energy produced by the units is transported for storage to a battery of 3.7V and 3200mAh (18650 battery: Total energy storage: 42624J).

The 18650 rechargeable 3.7V 3200mAh battery was chosen as the ideal battery due to its relatively small shape, capacity and its ability to be able to charge a phone at low speeds.

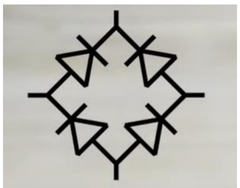


Fig 2: Bridge Rectifier

3. Generation of Electricity by the shoe.

During normal walking, whenever there is a pressure change on the Piezoelectric discs, voltage is generated about 1.5V to 4V realistically from one side. Although that is not its maximum voltage capacity, due to energy loss and inefficiency, the voltage generated from each configuration is about 1.5V to 4V. This is tested by strapping a multimeter connecting it up to each config and then noting the Voltage output on the steps walked.

So at a time, after the current passes through the rectifiers connected with the configurations C1 and C2 in parallel, the outcoming voltage becomes about 4V to 4.25V as noted by testing it using a Multimeter.

After the 4V is generated(In maximum cases due to maximum pressure at the shoe), the current now being changed from AC to DC, is then passed to a 3.7V, 3200mAh battery unit where the energy is stored.

Note: The current of the whole system is around 28mA (Checked using Ammeter)

However, is this really efficient? The calculations are shown below-

Multimeter Readings:

Current: 28mA

Voltage(Total): 4.25V (Tested and Calculated)

Formulas used:-

$E = VQ$

$1/R = 1/R1 + 1/R2$ ....(parallel)

$R = R1 + R2$.....(series)

$E = V*I*t$

Original AC Voltage = 4V
After rectification, peak voltage of the AC waveform before diode losses is :
$V_{peak} = V_{RMS} * \sqrt{2} = 4 * 1.414 \approx 5.65$

Voltage drop due to diodes (0.7V per diode)
$2 * 0.7V = 1.4V$

$V_{DC} = V_{peak} - 1.4V = 5.65V - 1.4V = 4.25V$

Current = 28mA (Multimeter Reading)

Power = Voltage * Current
$P = VI = 4.25V * 0.028A \approx 0.119W$

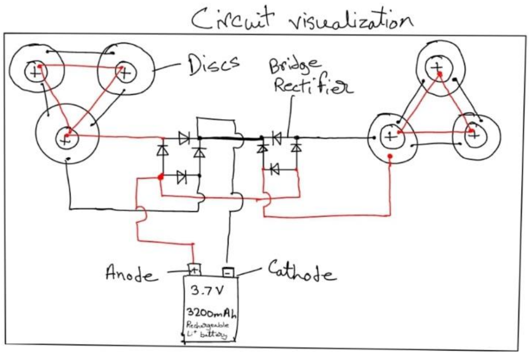
One step takes on average 0.5 Seconds

$Energy_{Step}$ = Power * Time
$E = Pt$
$E_{step} = 0.0119W * 0.5seconds = 0.0595$ Joules

Total Energy required for Li ion 3.7V,3200mAh battery: 42624 Joules
Number of steps required to charge the battery
$= ENERGY_{Battery}/ENERGY_{Step}$

Number of steps = 42624J/0.0595J ≈ 716,370 steps

It will take approximately 716370 steps to charge the battery.



3.1 Observations:

As can be seen from the above calculations, it takes about 7+ lack steps to actually be able to generate reasonable energy. But of course, there is one problem, it is not realistically possible for a person to walk 7 lakhs steps in a span of few day such that the energy generated is actually usable.

From this, there is one main thing we can infer. It is not efficient to generate electricity through shoes individually. Even if we take the energy generated by both legs during walking, It is still not sufficient enough to be used for everyday charging of devices.

3.2 Some Images of the Shoe

Fig 4: Circuit inside the shoe (sole removed)

Fig 5 : Side View of shoe (PCB attached to charge USB devices)

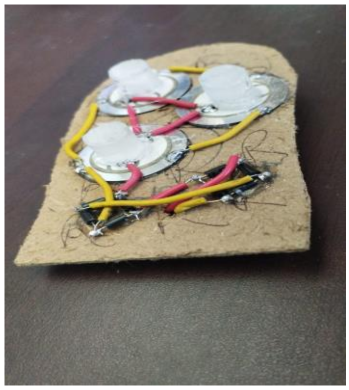


Fig 6: Basic Circuit (padding on top to protect disc and maximize voltage)

4. A Better Implementation (Costlier)

Advanced piezoelectric materials: By Switching from conventional piezoelectric materials to more efficient ones like lead zirconate titanate (PZT) or even composite materials that blend flexibility with high charge output could increase energy production per step.

Placement strategy: Adjusting the placement of piezoelectric discs based on pressure mapping of the sole to target high-pressure points, like the heel and ball of the foot, rather than a triangular formation.

Shock-absorbing layers: By adding a layer of Sorbitan that absorbs the shock from running, jumping, or doing any kind of physical activity will help increase the productivity and efficiency of the shoe.

Supercapacitor: A supercapacitor can help temporarily store charges from smaller voltage spikes and release them consistently to charge the battery, making use of even small energy outputs effectively.

CONCLUSION

In Conclusion, although piezo electricity generation through shoes is quite an intriguing idea, it is not practical if it is to be implemented for normal people who can actually afford the shoes. The sheer amount of effort it takes to charge a battery that can be charged in a much, much shorter amount of time using normal electricity further highlights the inefficiency of this product.

In the Future, further innovation and technology is required for these shoes to be practically feasible and usable. Thus there is a long road ahead for us when we live in a world that produces usable energy just by walking.

Further, this project demonstrates that there should be more focus on good sources of renewable and sustainable energy such as solar energy and wind energy in order for us to live in an idealistic world where no one will need to live in a lack of electricity.

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