Running to Charge

EXPERIMENTING WITH PIEZO ELECTRIC TRANSDUCERS

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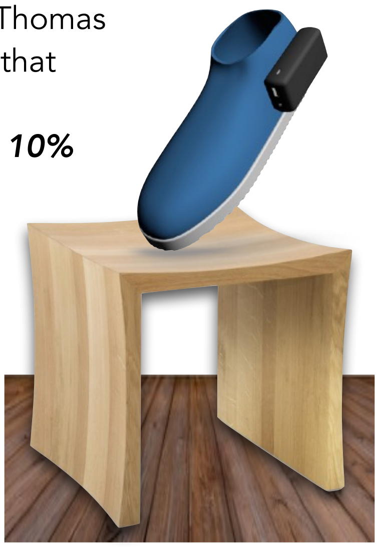
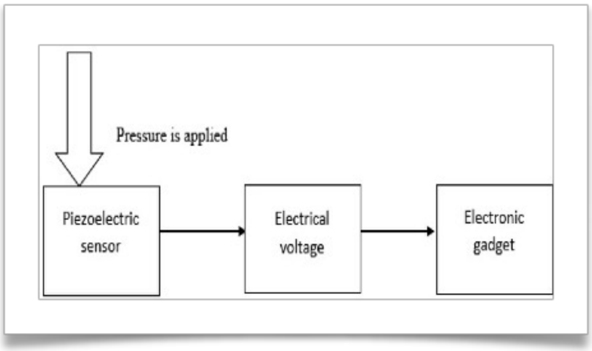
It is claimed that Thomas Edison once said that ***"Genius is 90% perspiration and 10% inspiration".*** This experiment taught me exactly that; you have to read the whole document to find out why.

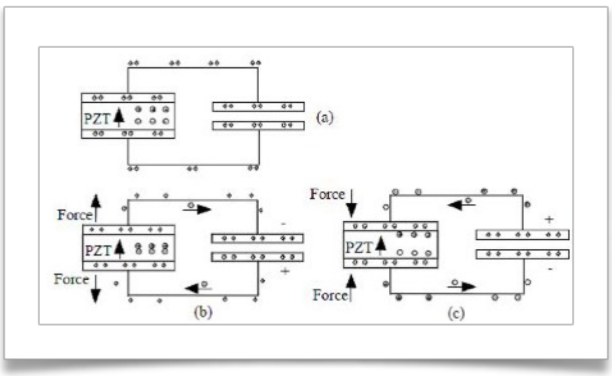


The Concept:

Piezoelectric materials act as transducers, converting mechanical signals into electrical ones and hence convert mechanical energy into electrical energy.

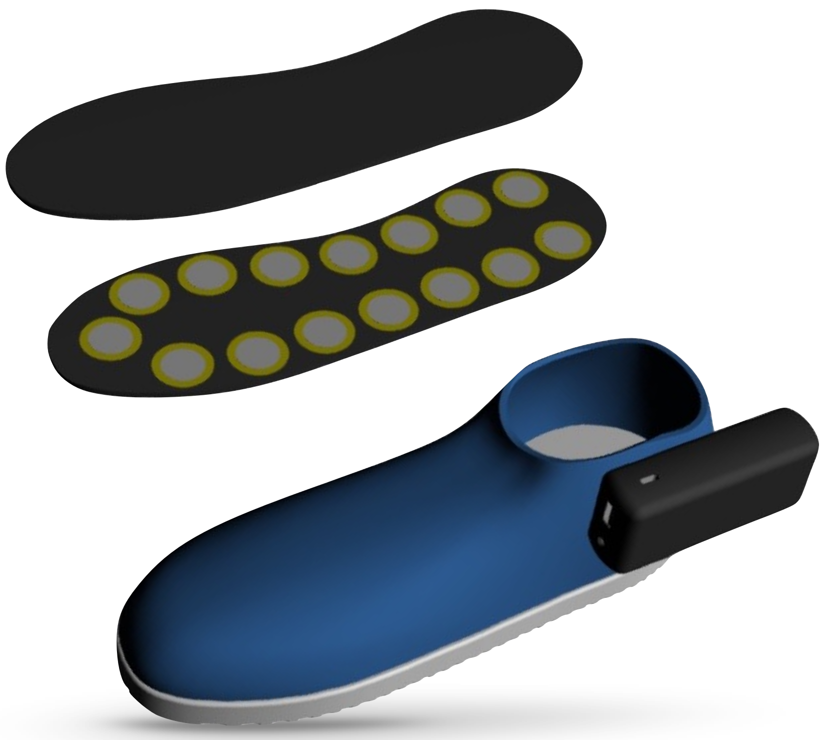


The piezoelectric effect is the generation of electric charge when mechanical strain is applied on piezoelectric materials. These piezoelectric elements are be made from natural quartz or Lead Zirconate Titanate (PZT) an artificial piezoelectric material.



PZTs are cheaper so that what I used. The PZT pads I could get were circular in shape, with a 27 mm outer diameter. Using several piezo-electric elements in one layer in the sole of a shoe we could generate about 4V DC. Using a voltage step up circuit this could be used to slowly charge a mobile phone or a USB battery pack.

Now we had to compute the amount of effort that would be required to produce enough electricity to charge a battery.



Variable	Symbol	Unit
V	Voltage across the piezoelectric cells connected in series	Volt (V)
I (DV)	Current across the piezoelectric cells connected in series	Microampere (μA)
P	Power in the circuit	Watt (W)
F	The force of the eccentric ruler which strikes the piezoelectric cells.	Newton (N)
A	The area of the piezoelectric cells being activated	$Metre^2$
T	The stress in the piezoelectric cells during activation	Newton $Metre^{-2}$
d	The piezoelectric strain coefficient of the ceramic cells which determines the current output per unit stress.	Newton $Volt^{-1}$ $Metre^{-2}$
D	The distance travelled by the ruler which strikes the cells each oscillation (from a maximum to a minimum)	Metre
t	The time taken for the ruler to complete one to and fro motion- an oscillation.	Second
v	The average velocity of the ruler striking the cells	Metres/ Second
RPM (IV)	The Rotations per minute set at the stall torque motor which causes the ruler to move and strike the cells.	Rotations/Minute

The theoretical equation helped us determine Voltage from stress by

Equation 1: ***V=d×T***

Where V was the magnitude of the velocity vector, d was the piezoelectric constant (11.2 in this case obtained from the dealer of the cells) and T was the stress.

We can rewrite the equation to allow us to measure force, where stress is force per unit area.

Equation 2: ***V=d×F/A***

Force can be expressed as power divided by the velocity of the ruler. The power can be calculated using the Voltage multiplied by the Current for each trial.

Equation 3: ***V=((d×P))/((v×A))***

Next, we can express the velocity as a function of RPM, where the velocity is determined by the distance travelled by the rod in 1 rotation. The rod travels a total of 10cm, 5 down and 5 up, every rotation. This is travelled every time period, given by the Rotations per second, which is simply the RPM/60.

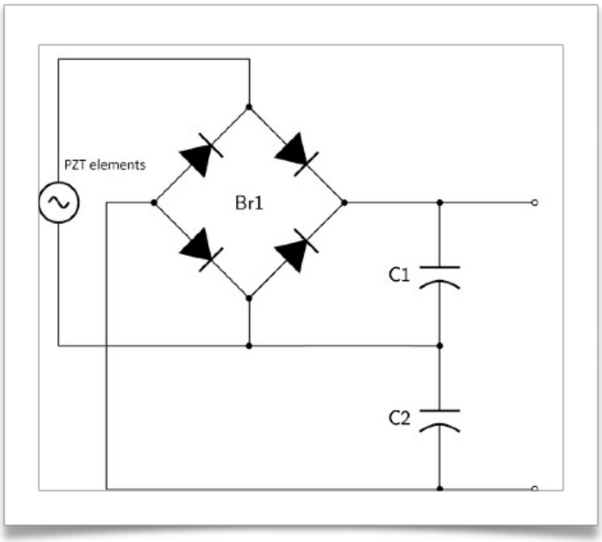
Hence, we get

Equation 4: ***V=((60× d×P))/((A ×(RPM) ×D))***

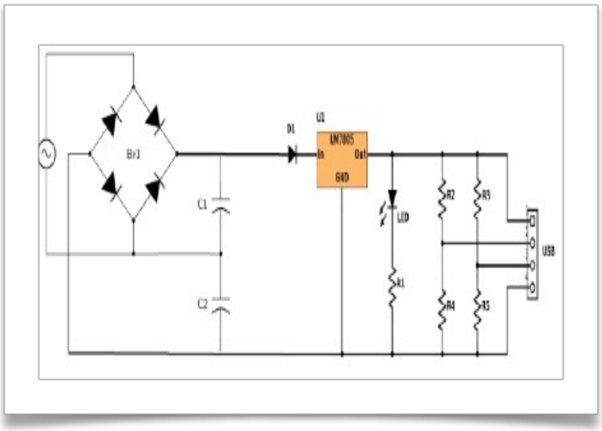
Lastly, the V cancels from each side, when Power is expressed as VI, to give the equation

Equation 5: ***I=((A × (RPM) × D))/((60×d))***

Where I is the current produced, d is the piezoelectric constant 11.2, A is the area of the top of the rod that strikes the surface given by 45mm2, P is the power dissipated per RPM, and D is the distance travelled by the rod in 1 rotation- 10cm.



The current generated from the PZT pads is alternating current (AC), since it changes direction each time a pad is pressed. However, the current used for recharging the batteries must be direct current (DC) meaning current direction and voltage polarity must stay constant. Direct current is necessary for storing energy in rechargeable batteries hence the alternating current has to be converted to direct current. This is done using a rectifier. A capacitor is added to smooth the ragged voltage from the bridge rectifier.



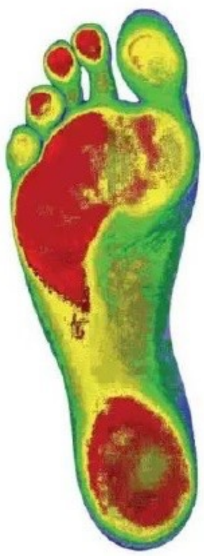
After the voltage is rectified to DC Charging circuits are used to regulate the voltage and current supplied to rechargeable batteries. If a battery is charged too fast or overcharged, it can overheat and explode. A charging circuit regulates the speed of charge to the battery and protect the battery from damage.

Parts used:

1. 2 shoes
2. 2 Li-ion batteries
3. 30 piezo-electric elements
4. 2 rectifiers
5. 2 voltage converters from 3V to 5V DC

Procedure :

1. I took a used sole of my shoe and from the usage pattern of the shoe figured out where I put most pressure (heel, balls, etc) on my foot. I then laid out the PZT transducers to cover all these areas as well as some areas where I did not put a lot of pressure but there was some pressure. In this way I determined that I could fit 13 PZT transducers in the sole of each shoe.



2. 4 pads were placed in the heel of the shoe, 5 pads were placed in the front of the shoe, and 4 more were placed between the front and the arch. No pads were placed on the arch because running or walking places minimal pressure on this part of the shoe.

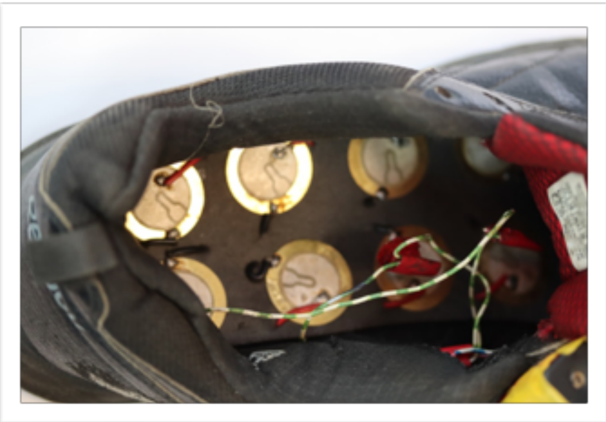
3. I then wired the PZT transducers in parallel to get the maximum voltage as my battery charging circuit required 3VDC. Even after using 13 transducers the power produced per step was very low. I realised I needed a mechanism that could replicate 1000s of step without tiring me out.

4. I used a motor to drive an eccentric shaft. This meant for each rotation of the motor's shaft I could get one "step" on the sole. If I spun the motor at 700 rpm I could get

700 steps per minute. I realised that no human can run this fast but as a proof that my schematic worked to charge a battery this would be good enough. Below is a chart of **measurements I got by varying the rpm of the motor.** I took each measurement 3 times and averaged out the voltage and current measurements.

RPM	Voltage (V)	Current (uA)
280	3.5	2.8
380	3.8	2.8
475	3.8	3.4
500	3.9	3.5
575	4.1	3.8
625	4.1	3.8
640	4.1	4.1
665	4.2	4.8
700	4.2	4.8

This was frustrating. I had wired 13 PZT elements in series there was a no increase in voltage. Similarly, wiring 13 PZT elements in parallel did not produce any increase in current. I needed to find out why I was unable to get more voltage from putting the PZT transducers in series or more current from putting them in parallel. **Then it struck me!** **EACH PZT transducer produce AC current and voltage and maybe one cannot add AC current and voltage** so I would need to **first convert the power** from **each of the PZT transducers** into DC **and then add them** (by putting the rectified power from the PZT transducers in series for more voltage and parallel for more current).



See "Running to Charge (in DC)" below for the result of this finding.

Another mistake I had done was to use a converter that could deliver 600mA which was not enough current to charge a mobile phone and could only charge a battery very slowly. I needed to find a charging circuit that was capable of delivering 2A at least to charge a phone

Conclusion: This project was very frustrating. I could not get enough power (VxA) from even 13 PZT elements to power a battery by regular walking. I had to use a motor operating at 700 rpm to get barely enough voltage and current to power a battery. I initially did NOT understand why wiring PZT elements in series does not increase voltage and wiring them in parallel does not increase current.

It was only at the end of the project when I realised that I was trying to add AC power and that I would first need to convert to DC and then add voltages and current. I really need to continue this project with 10-15 rectifiers for each shoe. However doing this would make the circuit in each shoe very big and complicated.

I also realised that I had ordered the wrong charger circuit and would need a charger circuit that can deliver more than 2A to charge a mobile phone. The circuit I had was limited to 600mA so could not charge a mobile phone and could charge a battery very slowly.

During all this research I found out that there are other real world applications for piezo-electric materials. If we embed these piezo-electric elements in our roads the mechanical energy exerted by the weight of passing vehicles can be converted into electrical energy. Since the weight of a car is about 1500-2000 kg and these cars travel much faster than humans on foot a lot more energy can be generated by this system than by the shoe-charger.

Running to Charge (in DC)

Further Experiments with Piezo Electric Transducers

As mentioned in The Shoe Charger above an accidental experiment of connecting each PZT transducers to individual rectifiers showed a substantial increase in power. The Improved Shoe Charger aims to use this finding to actually charge a mobile phone by walking/running.

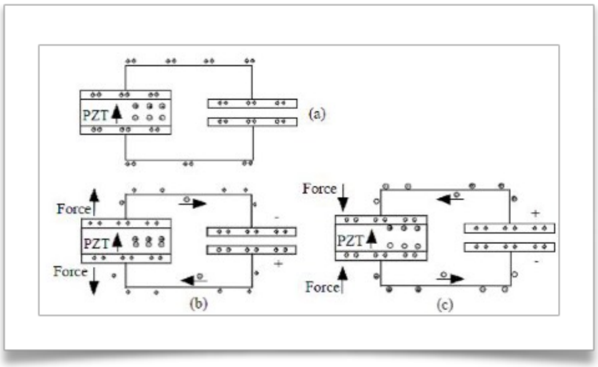
Concept:

To improve The Shoe Charger and produce enough power to charge a USB battery from a human running.

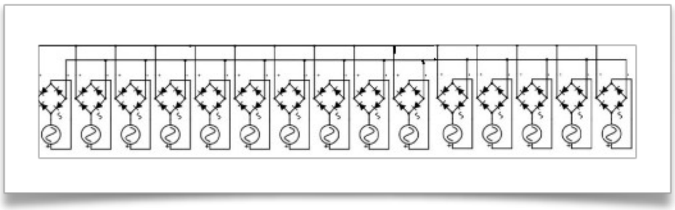
Parts used:

1. 2 shoes,
2. 2 Li-ion batteries,
3. 24 piezo-electric elements
4. 24 rectifiers
5. Lots of wire
6. 2 voltage converters.

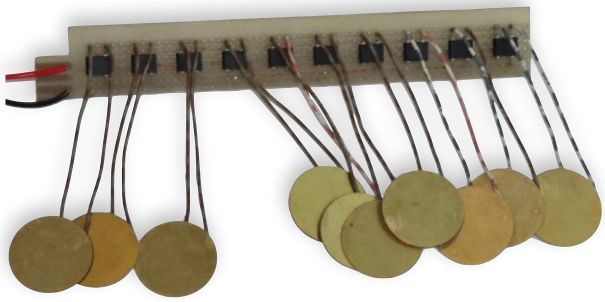
Date: July 2018



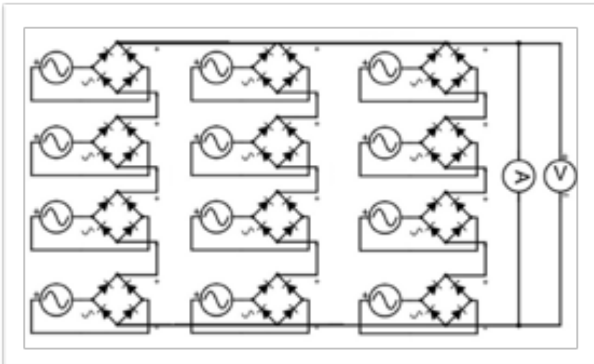
We already know that Piezo-electric elements can convert mechanical energy into electrical energy. We know also know that the voltage and current generated from the PZT pads is alternating current (AC) however, the current used for recharging the batteries must be direct current (DC). Moreover we learned that one cannot add AC circuits and expect them to double in voltage or current. You have to first convert them to DC.



I did an experiment. I took 10 PZT elements and 10 AC to DC rectifiers and wired up each PZT element to its own rectifier. Then I connected all the 10 rectifiers in series. When I measured the output across the summed rectifiers I got almost 20VDC. I knew I was on to something. If I can get 20VDC from 10 PZTs, I should get 8VDC from 4 PZTs then I can convert 8VDC to 5VDC and generate a higher current at 5VDC.

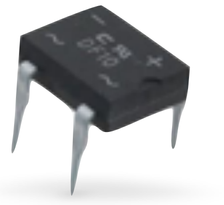


I could then parallel 3 8VDC circuits together to add the current. The goal was to reach 5VDC at 1A.



Procedure:

1. The design of the sole was the same as above, 4 pads were placed in the heel of the shoe, 4 pads were placed in the front of the shoe, and 4 more were placed between the front and the arch.



2. I then wired a compact rectifier circuit to each PZT element.
3. I took the output of all these rectifiers and filtered them through 2 capacitors.
4. Then I took the filtered output and connected that to a USB battery charger circuit that could generate 5VDC and 2A.

After using 12 PZTs each using its own rectifier I managed to get a lot of voltage but still not enough current. 60 micro amperes was not going to charge any battery or mobile phone.

Configuration	Rectifiers	Voltage (V)	Current (uA)
4 PZT in series	Common Rectifier	3.5V	2.8
4 PZT in parallel	Common Rectifier	2V	5.0
4 PZT in series	Individual Rectifiers	5V	8
4 PZT in parallel	Individual Rectifiers	8V	20
12 PZT in series/ parallel	Individual Rectifiers	24V	60

Conclusion:

There is an old adage "If at first you don't succeed try again". My father often tells me "you learn more from your failures, than from your successes because failures force you think and ask yourself what went wrong".

I realised that using PZT elements in a shoe could deliver adequate voltage but could not deliver adequate current. Unless PZT technology improves where each PZT element can produce about 0.1A (100mA) instead of the 2mA they produce now using PZT technology to charge a mobile phone is not going to be possible.

However I can see several small current applications. For example current GPS sensor modules need only 20-40mA to work. I am sure I can convert 24V/60uA into 5V/250uA to get some micro GPS sensor module to work. This GPS sensor could be used to track children in a playground, long distance runners who run 100km or troops in a battle field.

For example take this "Ultra High Sensitivity and Low Power GPS Receiver Module" from Skylab. It needs only 23mA in navigation mode and 7uA in back up mode.

http://sensorembedded.com/product_extra_files/skg13bl.pdf