Using Piezoelectric Crystals to Charge a Battery as a Form of Alternative Energy

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Abstract

This project deals with using piezoelectric crystals to create a form of alternative energy. Piezoelectric materials are sensitive to mechanical energy, such as tension and compression, as well as acoustic energy. When mechanical energy is applied to the piezos, all of the many dipoles of the crystal are polarized into one specific direction, thus creating an electrical charge. The piezo materials could be used to charge batteries with the correct components in between. The component most helpful in this situation is a switch-mode power converter. There are two significant types of power converters; linear and switch mode. A switch mode converter will be dealt with in this project. In the vast science of power conversion, there are two significant rules. Rule number one is that capacitors cannot instantaneously lose voltage. Rule number two is that inductors cannot lose current instantaneously. In a converter, when the switch is closed and opened, current runs through the inductor, and then it stops. Because the inductor cannot instantaneously lose current, that current converts to a quick and sharp voltage spike. This is the foundation of the switch-mode converter. In the converter, the switch opens in closes rapidly, sometimes hundreds of times per second, and the voltage jump is harnessed for power, while losing little energy in the form of heat. In the project, this, combined with the clean piezo power source, an alternative energy source will be created. A circuit was created with eighteen piezoelectric discs, and an AC to DC switch mode power converter. The piezos were used as an AC power source which, through the converter, would charge the DC six volt battery.

Introduction

Piezoelectric materials are quite underestimated substances that could serve many purposes. A piezoelectric substance is a material that is able to convert mechanical energy, such as compression and strain, into electrical energy (Resonance Pub 1998). Thus far, these crystals have been used mainly for amplifying sounds. They are found in microphones and instrumental pickups, but few people have put the piezos to more progressive ideas. The idea of harvesting physical energy and converting it into usable electricity has been touched upon, though a new idea that has been developed, piezoelectric wall and ceiling tiles, would take the research a step further and apply the energy harvesting to every day usage. The clean energy created by piezos, combined with switch-mode power converters, could be used to create an efficient and useful form of alternative energy.

History of Piezoelectrics

The concept of piezoelectric crystals was discovered in 1880, when two scientists Pierre and Jacques Curie (see Figure1), used their knowledge of pyroelectricity to conduct experiments that resulted in piezoelectric behavior (APC International, 2005). They discovered the effect in tourmaline, topaz, quartz, cane sugar, and Rochelle salt, though the quartz and Rochelle salt were the most effective (Piezo Systems, 2009). In the early 1900's, scientist Woldemar Voitg discovered 20 natural crystals that produced the piezoelectric effect (Piezo Systems, 2009).

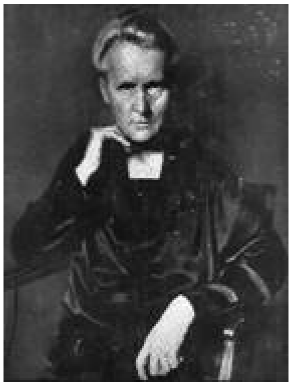


Figure 1.) Jacques Curie, discoverer of piezoelectricity and scientist for whom the Curie point is named (page 5)
http://www.tau.ac.il/~phchlab/experiments/QCM/Piezoelectric_History_files/image002.jpg

The crystals were nothing but a scientific curiosity until the piezos found their way to World War I, where the military used them in a sonar system. The sonar wave would be sent out, and a series of piezoelectric quartz crystals that were glued between two steel panels, a sort of satellite dish, would pick them up upon their return. Around the same time, piezoelectric crystals were used in phonographs. The use of piezoelectric ceramic phonograph cartridges increased the sound quality while decreasing the machine's price (Piezo Systems 2009).

During the World War II era, the piezoelectric materials were very important, though the people who used them needed more powerful materials. The need for a more powerful piezo led to the discovering of ferroelectric materials, or man-made piezos that produced far greater amounts of energy than the natural made materials. Some of these substances are barium titanate and lead zirconate titanate (Piezo Systems 2009).

Years later, piezoelectric crystals were being used in watches, microphones, and other devices. The most common use today is the microphone. The piezoelectric crystal acts as a note translator for the actual preamp in the microphone. Each note has a different frequency, and each frequency exerts a different amount of pressure (DeMasi 2005). The piezo absorbs the pressure of the sound wave and converts the pressure of the wave into electricity. The electricity then moves to the preamplifier, where it is translated into a note and sent to a speaker. Piezoelectric microphones are used mainly for acoustic instruments and vocals, because they create a much cleaner, clearer tone than magnetic pickups or lace microphones.

Along the same lines of the piezoelectric microphone, is a patented system used to install audio hardware. The system revolves around a 6 foot by 10 foot carpet and two radars. A series of sounds at different frequencies are played in a room, where they get picked up by the carpet, a series of piezoelectric wires covered in fabric, and sent to the radars. The radars read where the acoustics are strongest, weakest, which and which frequencies are amplified at which position. Once the data is collected, the audio system can be installed (Paradiso, 1997).

Another advance in piezoelectric materials is in the same category of the project being discussed. As a form of alternative energy, scientists have devised a suit with piezoelectric materials embedded in the fabric that hamsters wear. With each movement the hamster makes, the piezos in the suit pick up the mechanical energy and convert it to physical energy (Bourzac 2009). It is not the most efficient alternative energy source, though it has much potential for future studies and sciences.

Using piezoelectric materials for alternative energy is a relatively new study, and it has so far proved inefficient. The study conducted in this project improves on the idea, making it more efficient and realistic as a viable energy source. The piezoelectric effect is small, though if the idea is properly applied and the generated electricity is properly stored, such a system could carry much potential.

Piezoelectric Effect

There are two types of piezoelectric materials; mono-crystals and poly-crystals. Mono-crystals are very focused piezoelectric crystals, where all charge faces one direction. The mono-crystals are very small, and make up poly-crystals. The poly-crystals are made of many mono-crystals, each which has a charge that is faced in a different direction. Focusing each of the mono-crystals in the poly-crystal to make a singular charge is the piezoelectric effect (Aurelien, 2006). The piezoelectric effect can be obtained easily, when conditions for each piezoelectric material are correct.

The piezoelectric effect is a fairly simple physical reaction. When an electrical field is applied to the piezoelectric poly-crystal, the charge within each mono-crystal becomes perfectly focused in a common direction (Resonance Pub, 1998) . The poly-crystal must be heated or cooled to a certain temperature before the electrical field is applied, to allow the molecules of the mono-crystals to move more freely, so the charge has more potential to focus towards one direction. The focused charge of the mono-crystals is what gives the poly-crystal a piezoelectric property (see figure 3). When stress is applied to the piezo (strain or pressure), the mechanical energy that is created by the stress is converted into electricity (see Figure 2). From there, the electricity must be harvested otherwise it will dissipate (Aurelian, 2006).

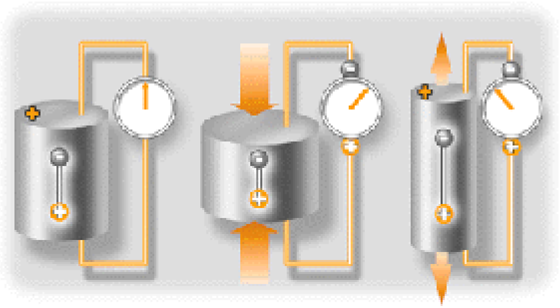


Figure 2.) The first cylinder is a piezoelectric material that is in a neutral state. The second cylinder displays compression, which gives off a positive charge. The third cylinder displays tension, which gives off a negative charge. http://www.keramverband.de/keramik/deutsch/fachinfo/image/piezoeffekt.gif

Temperature control of the piezoelectric material is the most crucial part of bringing the piezoelectric effect out of the poly-crystal. The piezoelectric material must be brought to a specific temperature where the piezoelectric effect is at its peak. Although most crystals must be heated, some piezoelectric materials must be cooled for them to function at their best. An example of this would be the man-made super poly-crystal, Strontium Titanate. Strontium Titanate is known for having the most powerful piezoelectric effect of all the piezoelectric materials. The only drawback to the substance is that in order to achieve this super piezoelectric effect, the poly-crystal must be cooled to 1.6 Kelvin, or -271°C (Resonance Pub, 1998). The temperature at which Strontium Titanate functions is the substance's most curious feature. All other piezoelectric materials cease to function at about 50 Kelvin, or -370°Fahrenheit. The super crystal functions at 86.8°Fahrenheit lower than most others (Resonance Pub, 1998.)

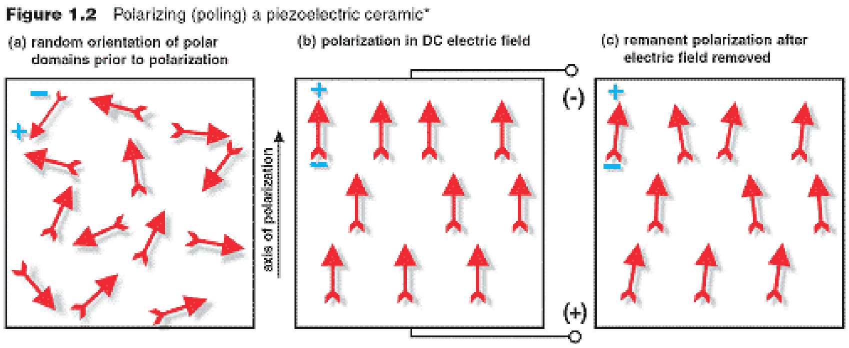


Figure 3.) (A) A piezoelectric poly-crystal. (B) When an electrical field is applied to the poly crystal, the poles of the mono-crystals become focused. (C) When The electrical field is removed, the pole of each mono-crystal is much more organized than it was in (A).
http://www.pc-control.co.uk/images/piezo2.gif

The Converse Piezoelectric Effect

For every action, there is an equal and opposite reaction. As mechanical pressure is applied to a poly-crystal electricity is received as an output. If electricity is applied to a piezoelectric poly-crystal, the output will be mechanical energy (see figure 4). With the focused poles of the piezoelectric crystal, one side is negative and the other is positive. If a negative charge is applied to the piezo's negative pole, and a positive charge to the piezo's positive pole, the result would be mechanical strain on the crystal. If a positive charge is applied to the piezo's negative pole, and a negative charge is applied to the piezo's positive pole, the result would be mechanical compression on the crystal. This reverse piezoelectric effect is simply called the reverse (or converse) piezoelectric effect. (APC International, 2005).

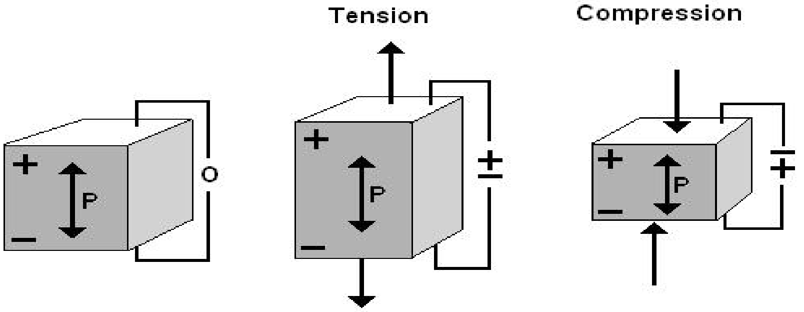


Figure 4) The first gray box is a piezoelectric poly-crystal with no stress exerted on it. The second box displays tension, in which same poled charges are applied to the corresponding poles on the poly-crystal, stretching it. The third box displays compression, in which opposite charged poles are applied to the opposite charged poles on the poly-crystals, compressing it.

http://bostonpiezooptics.com/files/NewDirectEffect.jpg

Structure of Piezoelectric Materials

Piezoelectric materials are not just any crystal or ceramic material. Each piezoelectric poly-crystal consists of specific structural builds that give it a piezoelectric property. Piezoelectric ceramics consist of symmetrical lattices. The inside of the lattice is generally a tetravalent ion (commonly titanium or zirconium), while the outer lattice consists of divalent metal ions (commonly lead or barium) (APC International, 2005).

Piezoelectric crystals work very similarly to the ceramics. The piezoelectric effect happens in symmetrical crystal lattices. In the lattices, the piezoelectricity of the poly-crystal depends on the Curie point of the mono-crystals. If a crystal is at temperatures is below the Curie point, then the magnetic domains do not line up, and the crystal has a magnetic charge. If the poly-crystal reaches temperatures that throw the crystal at or over the Curie point, then it no longer has magnetic properties because the magnetic domains are lined up and balanced. When the piezoelectric poly-crystals reach the Curie point and lose their magnetic and piezoelectric properties, they are considered paramagnetic substances. Ferromagnetic materials consist of more than piezoelectric materials. A ferromagnetic material is any substance with a magnetic charge. Each of these materials has a Curie point, in which the temperature balances out the magnetic domains and the material becomes paramagnetic. (Resonance Pub, 1998)

The piezoelectric materials used during this project are 1 inch piezoelectric ceramic discs. They produce about 10 volts, which is very good for a piezo of that size. Unfortunately, they only create about 0.001 amps of current, which could prove problematic during the testing of the project.

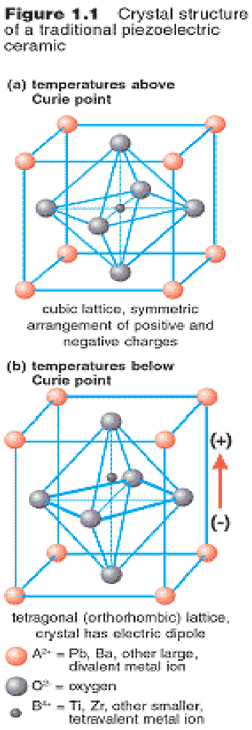


Figure 5.) (A) A piezoelectric ceramic lattice that is above the curie point. It retains a box shape and the central horizontal plane is flat. (B) A piezoelectric ceramic lattice that is below the Curie point. The central atom is off not centered, making the magnetic domains not aligned and the piezoelectric crystal has ferromagnetic properties. http://www.pc-control.co.uk/images/piezo1.gif

Capacitor

Capacitors are devices that are able to take on a charge and apply the charge to outside appliances. They are made of multiple layers of a dielectric insulator and metal foil. Each one varies depending upon the type of capacitor. The insulator could consist of anything from paper to porcelain, and the foil could be anything from aluminum to lead. The capacitors hold the charge with capacitance, or the ability to hold a charge. Capacitance is measured in farads, or more commonly microfarads (Brian 2009). One farad is a large amount of capacitance, and most capacitors cannot hold a charge that well, so microfarads are used. For example, a capacitor that is 10 microfarads will lose more of its charge over time than a capacitor rated at 20 microfarads. Capacitors also generally have very high levels of resistance, making it possibly difficult for the piezos to charge them.

Diodes

A diode is a semiconductive component often found in integrated circuits. Most diodes are silicon based, and serve many purposes (Hewes 2009). The diodes that are specified for the project at hand are rectifiers. Rectifiers are a type of diode that converts AC current to DC current by filtering out the negatively charged particles, leaving the positively charged DC current flowing in the circuit (Hewes 2009). The rectifier does that using the silicon inside, which has positively charged “holes” in it that trap the negative charges, only allowing the positive charges to continue flowing (Hewes 2009).

Switch-mode Power Converters

In the world of power conversion, there are two laws. The first is that a capacitor cannot instantaneously lose voltage. The second states that an inductor cannot instantaneously lose current (Billings 1999). Power converters are made of inductors, so the second law will be focused on. In a simple circuit that includes a power source, a switch, and an inductor, a peculiar phenomenon occurs when the switch opened and closed. With the switch closed, current runs through the circuit as it should. When the switch opens, the current that is in the inductor converts to voltage, creating a sharp spike of voltage in the circuit, which then returns to normal (Billings 1999). This happens because the inductor cannot instantaneously lose current. In a switch-mode converter this voltage spike is taken advantage of. The switch is opened and closed rapidly, producing many voltage jumps (Billings 1999). These jumps are harnessed, creating a more efficient power conversion than in the converter's counter part, the linear converter (Billings 1999). The linear converter releases much of its energy in the form of heat, making it less efficient and more difficult to maintain. The switch-mode converter does not build up heat, and produces more voltage, making it more efficient (Billings 1999).

Chemicals / Consumables	*Supplies*	*Equipment*
Wire Glue	10V Piezoelectric discs Copper Wire AA Rechargeable Battery Switch mode Power Converter	Multi-meter Paint brush

Procedure

To allow the electricity generated by the piezos to be stored in the battery and measured, a circuit was created in which the piezoelectric materials were linked to the switch mode power converter and the battery dock.. In order to build the circuit, the piezos needed to be connected to each other by opposite poles, or connected in a brass to ceramic pattern. Unfortunately, the ceramic bit of the piezos was flat and in the middle of the brass disc, seemingly inaccessible with alligator clip leads. The ceramic was also too sensitive for soldering. To solve this problem, a conductive adhesive was acquired which would hold the circuit together without damaging the piezos.

The piezo circuit was created by connecting the piezos together with 4cm strands of copper wire. The wire was glued to the ceramic side of the piezo disc and left to dry. Once the wire dried to the piezo, the wire was bent to make a hill to the next piezo; it could not lie flat, as the wire could not touch both poles. Once this was done, the free end of the copper wire was glued to the underside of the piezo disc that was to come after the previous in the circuit, making series circuit. At each end of the circuit, 15cm copper wire was attached to the piezo's free poles. The longer copper wire would connect to the switch mode power converter.

Once the circuit was made, it was connected to the switch mode power converter and the battery dock. The converter had a cable attached to it (the output), and it was trimmed down, stripped, and attached to the input of the battery dock.

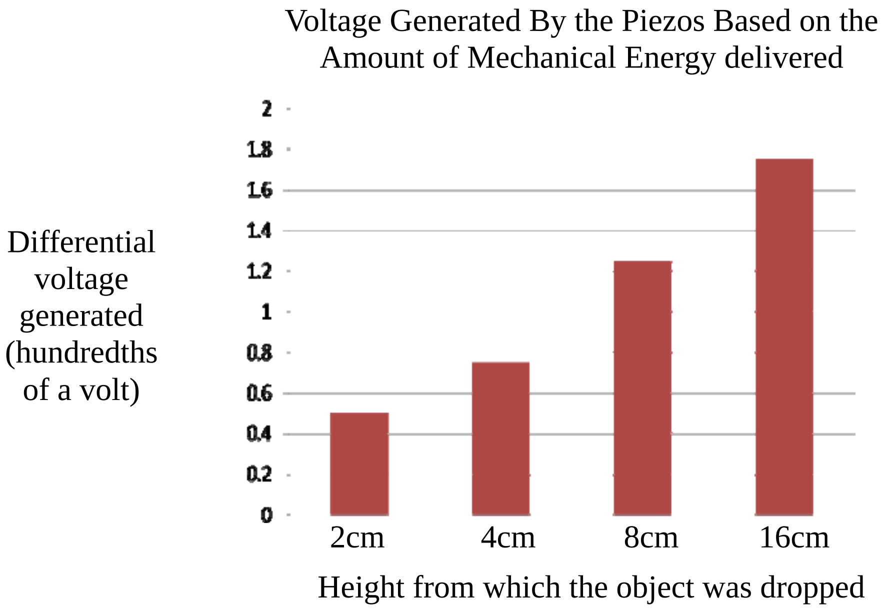
On the input side of the power converter, the 15cm copper wire from the piezo circuit was attached to each respective pole of the power converter, thus completing the circuit.

Testing the Circuit

Once the circuit was assembled, vibrations were passed directly through the piezoelectric materials. This was done by dropping a heavy object (in this case a screw driver) from 3 cm on the piezos at an even rate of once per second for 60 seconds. Three trials of this test were conducted, and the results were gathered based on the amount of voltage the battery gained since the last trial. The same test and measurement procedures were conducted, but the heavy object was dropped from 6 cm, twice the height of the first test.

Results

During the tests, light amounts of mechanical energy were submitted to the piezoelectric discs. Had there been more mechanical energy and less resistance in the circuit, the discs would produce their full piezoelectric potential of 10 volts each (90 volts), and would have charged the battery much more. The excessive amount of glue used on the circuit potentially added some amount of resistance to the circuit, taking away an amount of potential voltage from the battery, even if only a small amount. It took six minutes for each battery to gain 1/10th if a volt. The batteries are six volt batteries, and if left on the piezo circuit to fully charge, they would fully charge in six hours.



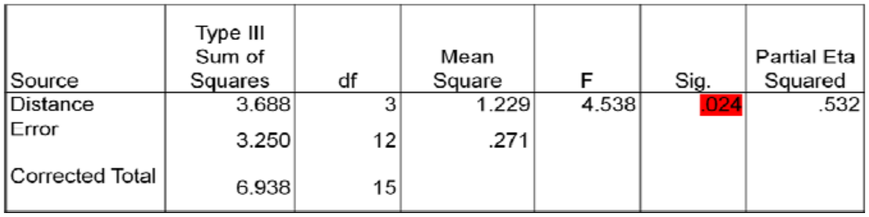
The graph above shows how much energy was gained on average during each test. The correlation between amount of mechanical energy applied and amount of energy produced can be seen between the 2cm and 16cm drop tests.

The chart below is a second way of looking at the data. Each value for each trial shows how much voltage was gained during each test. Each voltage increase from the previous test was treated as zero and only the voltage gain from the next test was recorded.

Voltage gain	Trial I	Trial II	Trial III	Trial IV	Average
2cm	0.01	0	0.01	0	0.05
4cm	0.01	0.01	0.01	0	0.075
8cm	0.01	0.02	0.01	0.01	0.0125
16cm	0.01	0.02	0.02	0.02	0.0175

This data was then put into a statistics test to see if there was any real change in voltage between the 2cm and 16 cm tests. The red number, .024, is the percent similarity between the 2cm and 16 cm. Test. If the number is below .05, then the tests are statistically different from each other.

Dependent Variable: VAR00001



Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Distance	3.688	3	1.229	4.538	.024	.532
Error	3.250	12	.271			
Corrected Total	6.938	15				

a R Squared = .532 (Adjusted R Squared = .414)

Multiple Comparisons

Height	Correlation	Mean Difference	Std Error	Sig.
2cm	2.00	-.25	.37	.903
	3.00	-.75	.37	.228
	4.00	-1.2500(*)	.37	.024
4cm	2cm	.25	.37	.903
	3.00	-.50	.37	.546
	4.00	-1.00	.37	.077
8cm	2cm	.75	.37	.228
	2.00	.50	.37	.546
	4.00	-.50	.37	.546

This is a second representation of the statistics test, which shows the correlation between the 2cm test and the others which can be seen by the 2cm tests highlighted.

The results show that the piezos do create some measurable voltage, and that the more mechanical energy applied to them, the more energy that is created.

Conclusion

Piezoelectric materials have proven their potential in the world of alternative energy sources. They can produce measurable amounts of clean energy, which is a very important detail in the modern world of alternative energy. With some tweaks, the circuit could be used commercially. Possible areas of application could be subway tunnels, air ports, schools, or other places characterized by high levels of noise or foot traffic. Anywhere in which there is an abundance of mechanical energy could be a place where piezoelectric materials could be used for electricity.

The circuit is not at it's prime yet, though, and many changes would need to be made before it could be applied to to such places. The piezoelectric materials being used are very weak, and could barely overcome the resistance of the circuit itself, which is relatively low resistance in the first place. The PZT piezo materials being used could be replaced by more powerful lead or boron based piezoelectric materials. The material used for the wiring could be changed from copper to gold or silver, both of which have lower resistance than copper. For commercial purposes, an AA battery would not be useful, as it is too small. The piezo circuit would have to be made and tested on a larger scale with a larger battery if any definitive and comparable results are to be produced. The final problem with the circuit was the adhesive used to hold the circuit together. It would not be able to last long on a commercial scale, because it is very brittle and difficult to use. It takes extensive amounts of time to dry, and becomes very easy to break once it has dried. The circuit used during the experiments required consistent re-gluing, at various points throughout the tests.

Because of this, the results are not very definitive. The circuit was constantly remade with different amounts of adhesive and different placements of the wire on the piezo. This could have greatly obscured the results gathered during testing. Multiple trials were conducted, but the more times the test was run, the more modification was made to the circuit, making the results poor in quality. Conductive adhesive tabs are reusable nylon/wire mesh tabs that can be stuck to the piezos and would not fall apart like the conductive adhesive glue. These could be utilized to make the results more definite in future studies.

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