Design Prototyping of Piezoelectric Energy Regeneration System

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Abstract - *With the increase in demand for energy sources, researchers are looking for energy generation through various means. One of the most unique and revolutionary ways is the use of the human body. The human body is an innovative way to produce sustainable energy that can power electronic devices. The energy which humans produce is dissipated into the environment and is hence available at no cost. Also, the advancement in technology has made it possible to use sensors that have high efficiency and negligible power consumption. Each step a human take can be used to produce electricity. This paper focuses on the production of electricity by the piezoelectric effect. For this, we place a piezoelectric sensor in the insole of a shoe, for every step the human takes there is a force equal to body weight applied to the ground through the shoe. Thus, by placing a piezoelectric sensor in the sole the applied force causes a compression of the shoe sole which actuates the sensor. Hence, we get an electrical output by the piezoelectric effect. This electrical output is in alternating form and is converted to DC which is further amplified using an amplification circuit that charges a battery. This method of producing electricity is highly efficient and durable. The technique of not using a power source and producing electricity in order to store it in wireless devices is called energy harvesting.*

***Key Words*: Charge generating shoe, piezoelectric effect, AC-DC conversion, an amplification circuit, energy harvesting, energy storage**

1. INTRODUCTION

The advent of technology has been a boon for everyone. Greater the technological inventions greater is the demand for electric supply. Researchers are focusing on the development of systems that have high energy efficiency, easy energy recovery, and systems that can convert different forms of energy into electrical energy conveniently. This has led to the creation of a variety of wearable devices. Researchers are tracking human activities closely; they are looking at all minute aspects from which energy can be created. This has given rise to wearable devices. However wearable devices need a power supply and an electrochemical battery is the most common one used. Although, the scope of electrochemical batteries is very limited because they do not have sufficient energy capacity storage for the size used in wearable devices. Hence our research is focused on using mechanical energy from humans and converting it to electrical energy. We are using the piezoelectric effect for the conversion of energy because it does not require an external power source, the sensing element is not affected by electromagnetic interference and radiation, it has a low cost and can be used under harsh conditions also. Due to these reasons, we have focused on selecting the piezoelectric effect. So, whenever humans walk the force applied by him causes mechanical stress applied on the crystals. This stress leads to the generation of an electric charge across the faces of the crystals. This can be measured as a voltage proportional to the applied pressure. As you can see, we have generated electrical energy without an external power source. This method of energy harvesting is trending and attracted many people to do revolutionary innovations in this field. The voltage produced is stored in a battery that can be used to charge various electronic devices like mobile phones, laptops, etc. Since we are getting low voltage output, we intend to use an amplification circuit to amplify the output voltage. Thus, giving us a large final output. The placement of the piezoelectric crystal will be decided by a load cell. The load cell will help us show where maximum force is distributed and accordingly, we will place our piezoelectric crystals.

Thus, our research focuses on the dissipation of energy by humans walking and converting that into a sustainable and rich form. We believe the problem of low output voltage generally caused by the piezoelectric effect will be resolved with the use of our amplification circuit. The use of wearable devices is gaining attention and such methods are not only cost-effective but also environment friendly. The scope of wearable devices is a lot, people can implement it in various items used by humans in day to day life.

2. LITERATURE SURVEY

Energy conservation has become one of the most important criteria. Energy conservation is of utmost importance and generating charge from any possible source would result in saving of electricity for further use. Based on this, we came up with the idea of generating charge and charging batteries without the use of electricity using the pressure applied by the person on the ground. We researched regarding various projects and research paper in the similar domain. Also, we came across projects and papers that helped us find out the issues and difficulties that we could face. The problems such as placement of the piezo electric sensor inside the shoe, placement of the electronic circuitry and also the battery to be charged was resolved through research papers and various other similar kinds of project. Research on different materials of the piezo electric crystal was done and the one best suited for the project was selected. Research regarding the sole of the shoes was also done for better results. If the sole material is easily compressible the force applied will compress the sole rather than the piezoelectric material. Battery to be charged was also selected depending on its weight and cost. In order to make the product cost effective and productive, basic components are used.

3. EXPERIMENTAL RESULT

We have simulated the project on software to determine whether the voltage generated by the application of human pressure on the ground is sufficient to charge the battery or not. On application of pressure on the piezo sensor certain amount of voltage was generated. The voltage generated by one piezo was equal to 1V peak to peak AC voltage. So, in order to increase the AC voltage generated, 5 piezo sensors were connected in series. 3 piezo sensors were connected at the end portion of the sole and 2 piezo sensors were placed at the front portion of the shoe. It can be seen from the table that, the voltage produced at the front end was 2.5V AC voltage and at the end portion was equal to 4V AC voltage. These in the end were connected in series. This resulted in total AC voltage to be around 6.5V peak to peak. This AC voltage was converted into DC voltage using the voltage rectification circuit. Obviously, there were some losses during the conversion. The efficiency turned out to be 80% while converting the voltage from AC form to DC form. The DC voltage generated as an output was found to be 5.2V. As the voltage generated was not sufficient enough to charge the battery, further we used boost converter which is basically a voltage regulator that generates an output voltage up to 12V depending on the input voltage. This generated amplified DC voltage was given to the rechargeable batteries for charging the battery. Thus, with an efficiency of 80% the applied pressure was converted into voltage for charging purpose.

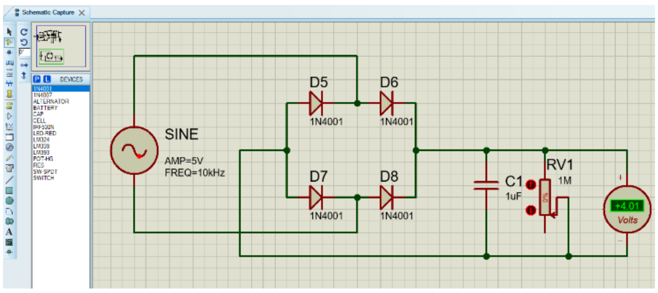

Figure 1. Simulation for conversion of AC voltage to DC voltage

4. DESIGN AND WORKING OF PIEZOELECTRIC SHOE

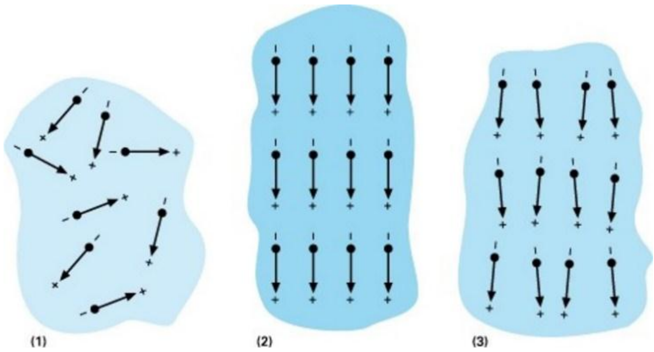

Figure 2. Unpoled Ferroelectric. (2) during (3). after poling

The piezoelectric crystals are actuated by mechanical strain. Mechanical strains cause deformation of the material. This deformation within the mechanical system causes generation of charge in active materials. Mechanical Vibrations are a major source of charge generation in today's generation. Piezoelectric materials have crystals that have a **specific** asymmetry. Some of the crystals used are that of quartz or tourmaline. Regular crystals have an organized structure which are repeated after some intervals. Whereas in asymmetric crystals the lattice points are irregularly placed and there is no definite pattern. When they are subjected to a strain the structure deforms and the atoms get distorted in a manner through which they can conduct electric current.

Now, having understood the generation of piezoelectric effect. The question arises as to how are we going to obtain mechanical strain, for actuating piezoelectric effect from walking. The human body consists of various bones, muscles, fats and various other substances which add up to a certain mass. This mass multiplied by gravity gives the force exerted by us on the ground. While walking the weight of our body acts on our feet, we use this force to cause a strain on piezoelectric crystals that are made of active materials.

Following this, we need to answer the question where do we plan to place the piezoelectric crystals and circuitry. The placements of the crystals depend where we get maximum mechanical strain. In order to get accurate results regarding weight distribution we intend to use load cells. Load cell is a force transducer that converts force into an electrical output. We have used a strain gauge type load cell.

Stain gauge load cell comprises of a solid metal body on which strain gauges have been attached. The body such that it undergoes slight deformation when load is applied and when overloaded it can return to the original shape. The strain gauges are connected in a Wheatstone bridge, that balances two legs of the circuit. Hence when a load is applied it causes deformation of the strain gauge which in turn causes a change in electrical resistance. This electrical resistance is proportional to the strain applied that is measured in terms of voltage change. Thus, we used a load cells to determine how pressure is generated while walking and the equivalent voltage produced. The values can be seen in the table provided.

Table 1. PRESSURE ANALYSIS

Pressure Points	Pressure Analysis		
	Time Interval	*Pressure generated*	*Voltage generated (AC voltage)*
Front portion of shoes.	20 mins	50Kpa	2V
	40 mins	55Kpa	2.4V
	1 hour	60Kpa	2.8V
End portion of shoes.	20 mins	70kpa	3.5V
	40 mins	75kpa	3.8V
	1 hour	80kpa	4V

Now, we have received data as to where the maximum force applied while walking, therefore placement of the piezo electric crystals can be determined. We will place the sensors where there is maximum strain produced or in other words where there is maximum pressure. The piezoelectric crystals will be placed on a plastic base using hot glue and the circuit is connected. This plastic base will be placed in the shoe. Since plastic is a hard material that will cause hindrance while walking proper cushioning needs to be provided. A normal shoe insole can do this job. Hence after placing the plastic base we cover it with the insole provided with the shoe. Thus, we have successfully placed our crystals that will help us generate electricity by mechanical stress.

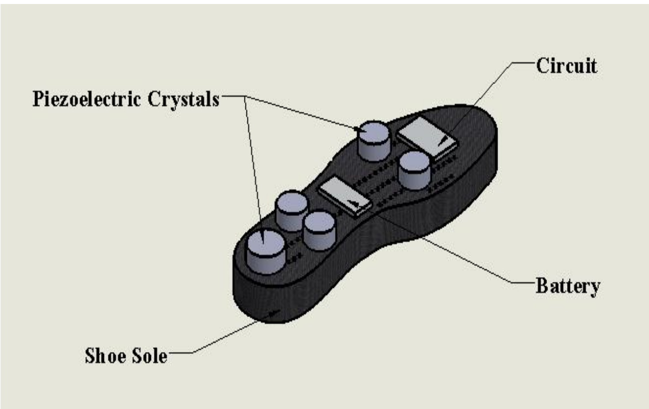

Figure 3. Design of Shoe

4.1 Electronic Aspect

The piezo electric transducer is a pressure transducer. The piezo material when applied mechanical stress, undergoes compression or expansion. The compression and expansion of this piezo material induces voltage that can be used to charge up the battery. The output voltage from the piezo electric sensor is given as input to the voltage rectification circuit which converts the AC voltage to DC voltage. After rectification, the DC voltage produced, is regulated using integrated chips or boost converter. The amplified voltage is then given to the rechargeable batteries for charging the batteries. The output voltage usually generated by a single piezo sensor is around few hundreds' millivolt to ten's volt depending upon the type of piezo material in the piezo sensor. This voltage is not sufficient enough for charging the battery. In order to achieve higher voltage, 4-6 piezo electric sensors are connected in series i.e. the output of all the piezo sensors is added and then given to the rechargeable battery for charging.

4.1.1. Flowchart

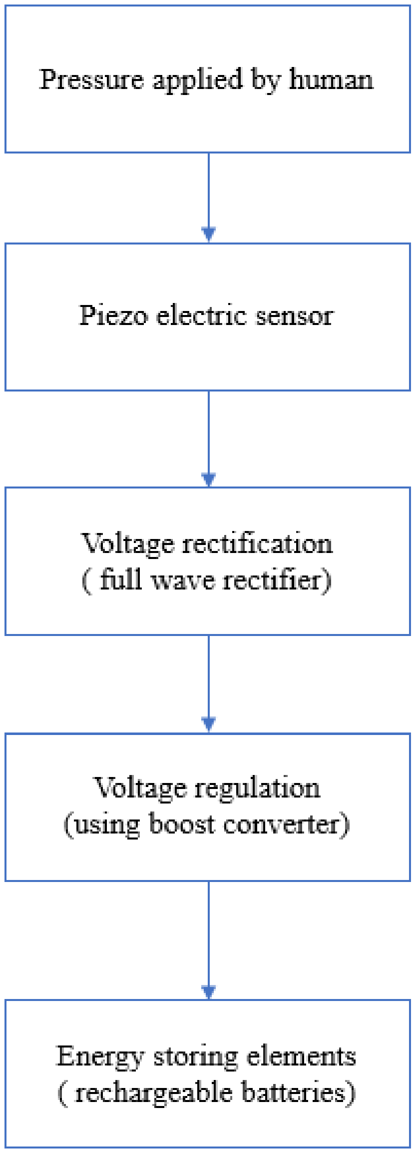

Figure 4. Recharging of batteries using piezo electric crystals

4.1.2 Final Circuitry

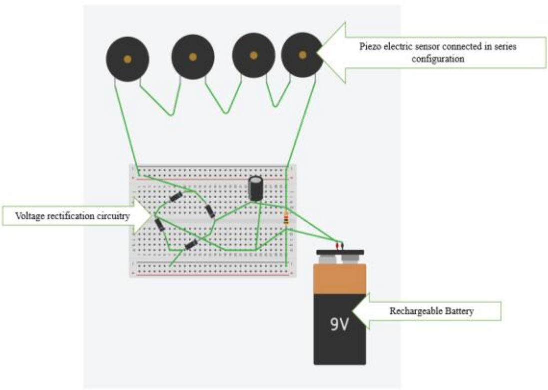

Figure 5. Final working circuitry

4.2. Piezo electric sensor

The piezo electric sensors work on the piezo electric effect. Piezo electric materials have an amazing characteristic of producing electricity while piezo electric sensors are transducers that are used to convert the mechanical force or pressure into equivalent voltage. The compression or expansion of the piezo crystal is sensed by the sensor and as an output, the sensor produces a fluctuating AC voltage.

The piezo electric sensor consists of a piezo crystal inside it which undergoes compression and expansion. Quartz crystal, rochelle salts, Barium titanate, lead titanate etc are some of the piezo electric materials.

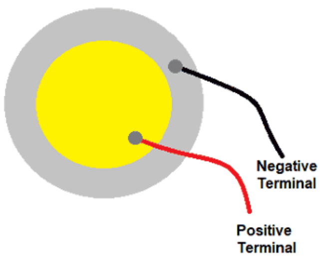

Figure 6. Typical piezo electric sensor

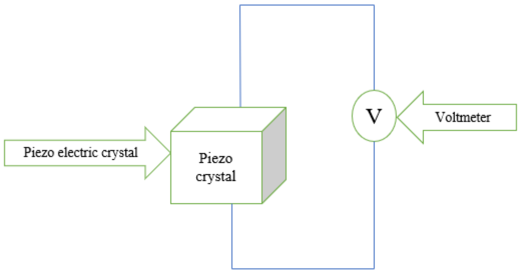

Figure 7. Basic piezo electric functioning

The polarity of the charge depends on whether the crystal is expanded or compressed as shown in the below figures.

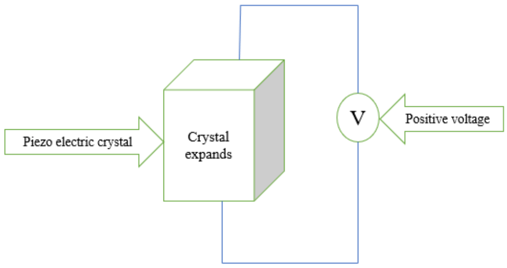

Figure 8. Expansion of crystal causing positive polarity of the charge (battery)

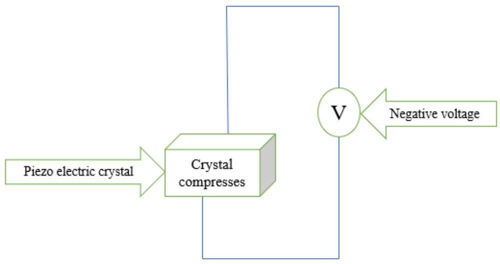

Figure 9. Crystal compression causing negative polarity of charge (battery)

4.3. Voltage Rectification

Voltage rectification is the process of converting the fluctuating AC voltage to corresponding DC voltage. The rectification takes place with the help of diodes and capacitors. Half wave rectifier and Full wave rectifier are the two methods of voltage rectification. The purpose of choosing full wave rectifier over half wave is, it produces higher average DC voltage with more smoothness.

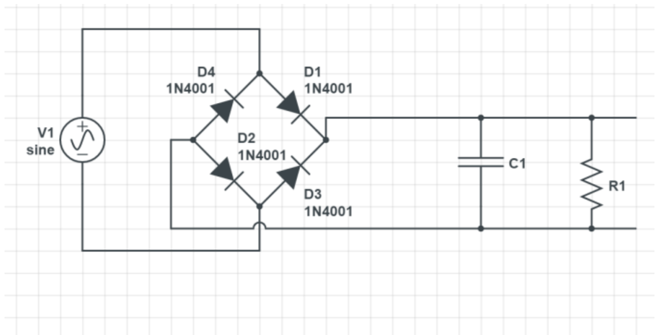

Figure 10. Full wave bridge rectifier for voltage rectification

In full wave rectifier, we have used four diodes, two for positive half cycle and the other two for negative half cycle along with a transformer and a smoothing capacitor for removing the ripples and producing DC voltage with 100% efficiency. The four diodes are connected in bridge configuration. This is called as full wave bridge rectifier.

During the positive half cycle, diodes D1 and D2 are forward biased whereas D3 and D4 are reverse biased, hence only D1 and D2 conduct the current i.e. allows the passage of current. Similarly, diodes D3 and D4 are forward biased whereas D1 and D2 are reverse biased during the negative half cycle, causing the allowance of current in the circuit. Thus, with the help of four diodes entire wave is passed and rectified. Capacitor is added in the circuitry for smoothening the ripples, so that there is no error produced during rectification.

4.4. Voltage Regulation

Voltage regulation is the process of amplification of the DC voltage. As the output produced, is not sufficient enough to charge the battery, voltage regulation is required. Voltage regulation circuit has the ability to provide constant voltage as output.

It provides constant voltage as output. There are many IC's or boards that regulate the voltage. LM7805, boost converter board, buck converter etc. are some of the examples of voltage regulators.

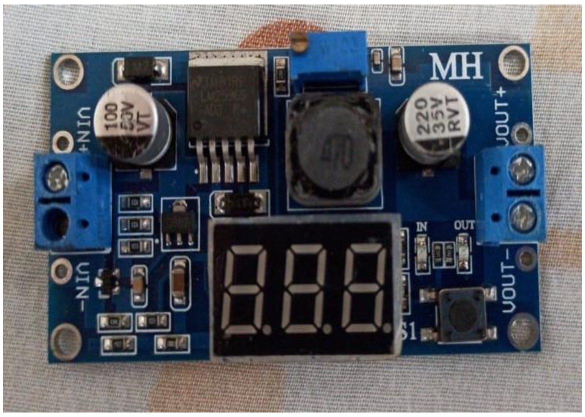

Figure 11. Voltage regulator module (boost converter)

LM7805 is voltage regulator IC which provides 5V constant voltage along with 1A current. The problem of using IC is that it requires about 7V to generate a constant voltage of 5V and current of 1A, which is not feasible. To avoid this, we use boost converter. Voltage boost converter does not have any constraints on input voltage. It converts the input voltage less than 12 volts to a constant voltage level which is 12 volts, which helps us in charging the battery. The module has an inbuilt potentiometer, which can used to adjust the output voltage level according to our requirement. In comparison to IC's, it does not require external power supply to operate. Thus, saving energy which is the primary purpose of this project.

4.5. Charge storing elements

Capacitors, batteries can be used for the purpose of storing the charge which is developed because of the change in pressure experienced by the piezo electric sensor. The stored charge can be further used to charge any of the electronic gadgets.

Capacitors are used for storing charges temporarily, whereas rechargeable batteries can be used to store the charge and then provide it whenever necessary.

Figure 12. Rechargeable battery

Rechargeable batteries are available in different sizes according to the requirement. Lithium ion (Li-ion), Lithium ion Polymer (Li-Po), Nickel Cadmium (Ni-Cd), Nickel Metal Hydride (Ni-MH) etc. are some of the rechargeable batteries that can be used.

5. CONCLUSIONS

This research shows how piezoelectric effect can be used to produce electrical output from mechanical stress and strain. This research is done on theoretical basis. We have thus designed a system that can produce electricity by human movement and transfer this power to a device. This system will help humans to charge their devices whenever they are out in the open and no charging points are nearby. Every human wish that they should have charged their phone more in the morning before going for work; by using these shoes they can charge their phone at their own time and anywhere in the world.

The idea of generating electricity from human motions is increasing rapidly. This is because the energy produced is sustainable and extremely clean. There will be any ways in future where many devices will be running by the energy provided by humans.

6. FUTURE SCOPE

Piezoelectric effect has many applications through which large and sustainable energy can be produced. We can use the concept of piezoelectric effect on roads, car tires, and tiles. The output received from the materials can be used to power buildings, street lights and charge various electronic devices in motion. Piezoelectric crystals placed in car tires can produce sufficient energy from one rotation and this energy can be used to charge batteries of future electric vehicles.

The shoes model we have described can also be improved by making the entire sole of piezo material rather than using crystals at certain locations. By doing so the circuit to the user while walking. Customizing the shoe to a rather fancy outlook will help us attract more customers. Thus, there is a large scope of using piezoelectric effect that made us more inclined to do something in this field.

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