International Journal of Research in Engineering
www.engineeringpaper.net
Online ISSN: 2664-8784; Print ISSN: 2664-8776
Received: 06-05-2019; Accepted: 09-06-2019; Published: 16-06-2019
Volume 1; Issue 3; 2019; Page No. 19-23

Laboratory characterization of a footstep energy harvest piezoelectric device for mobile phone charging

Hadiza Sani Sulenjebu[1], Abdullahi Lanre Amoo[2], Salihu Alhaji Abdul[3]
[1-3] Department, Electrical and Electronics Engineering, Abubakar Tafawa Balewa University, Bauchi, Nigeria

DOI: https://doi.org/10.33545/26648776.2019.v1.i3a.19

Abstract
Today, energy has become a necessity for everyone around the globe. The ever-growing number of electronic devices has increased the rate of energy consumption. In a bid to meet this demand, all sources of renewable energy must be maximized. This paper aimed at generating electrical energy by converting mechanical energy from human footsteps or vibration from machinery into electricity using piezoelectricity. This energy was collected in the form of ac electricity and stored in batteries; which was then used to charge a mobile phone. A piezo tile comprising 16 piezo crystal was constructed via series-parallel combinations. The piezo tile showed different reactions to varying weights. These reactions were apparent in the plot of average voltages generated versus weights as well as analytical formulation and thus concluded that more weight produces more power and vice versa.

Keywords: electromechanical coupling, energy harvest, *Piezo-electricity*, renewable energy

1. Introduction

The demand for energy is unquenchable as it continues to increase day by day [1, 4]. Undoubtedly, non-conventional methods of electricity will be the viable solution to upturn energy-demand deficits. Since 1970s energy crisis that resulted into cascaded outages in USA, the efforts to seek for alternative energy resources have been invigorated. Most commonly used methods are electromagnetic, thermoelectric, electrostatic or piezoelectric generators. In the renewable footstep energy harvest using piezoelectric device, the compendium of recent works is provided in Ref [2]. An average person weigh could generate tenth of watt within a second required of take two steps across the tile and by rule of proportionality in a large area of floor space where thousands of people are stepping or jumping will produce significant amounts of power which can be stored in large capacitors or batteries [5, 6]. This is the motivation of this research, an initiative that is capable of generating power through footsteps as a source of non-conventional energy obtainable while walking on certain paths or platforms like footpaths, stairs, markets etc. This is a setup that would derive energy from pounding feet in crowded places. With the population of Nigeria and mobility of its masses in places like Lagos, Kano and Kaduna, useful energy can be obtained by turning the mechanical motions into boon in generating electricity. Generally, human locomotion in over crowded subway stations, railway stations, bus stands, airports, temples, world religion gatherings in Mecca and Medina, rock concerts or world cup tournaments can be converted to electrical energy with the use of this promising piezo-electricity technology.

As the population of every nation increases, the demand for electrical energy increases proportionately. However, the growth Of power is constrained by many factors. More specifically in Nigeria where only 40% of its population are connected to national grid [7] with available capacity inefficiently dispatched to the extent that the served power downturns installed capacity as shown in Figure 1. In this scenario, there is need to generate more energy in addition to the conventional sources most preferably using renewable energy. The foot-step energy generation is characterized as a non-conventional source of energy.

Footstep energy generation can be an effective method to generate electricity. This paper aims at taking advantage of Walking, (which is one common activity in human life) to generate power through footsteps as a source of renewable energy that can be obtained while walking on a certain platform. This system can be installed in densely populated areas. It is mainly to devise a means of generating electricity using non-conventional means by converting force energy of human weights or vibration of machineries into electrical energy using piezoelectric sensor. The piezoelectric sensor is a transducer which converts force (mechanical energy) into electrical energy. In order to accomplish the aim of this work, the following objectives were carried out:

1. Piezoelectric sensor characterized as a transducer to convert force energy into electrical energy.
2. Force applied on the series-parallel connection of transducers converted into electrical energy to charge a mobile phone.
3. Voltage generated by piezoelectric sensors was fed into circuit elements of the appropriate output.
4. Output voltage was measured using an oscilloscope and multimeter.

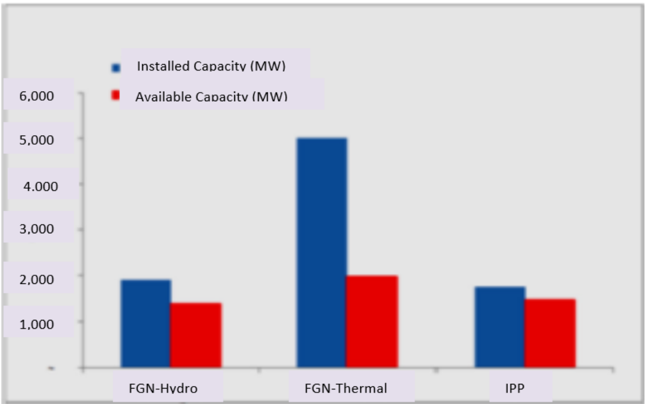

Fig 1: Nigeria Power Outlook [7]. (FGN Stands for Federal Government of Nigeria and IPP- Independent Power Producers)

2. Research Method

Under this section the basic theoretical background of the work are discussed. The piezoelectric material generates electric output when pressure is applied on to it but could also have reversible effects producing mechanical strain with passage of current. In the design for non-conventional generation of electricity, the source of pressure can be either from the weight of the moving vehicles or from the weight of the people walking over it. The output of the piezoelectric material is not a steady voltage, thus a bridge rectifier circuit is used to convert this variable voltage into a constant voltage source. Figure 2 shows the block diagram of the piezoelectric converter comprises of a storage rechargeable battery, rectifier, voltage regulator and a port of USB to charge mobile phone. As the power output from a single piezo-film is extremely low, combination of few Piezo films was characterized. The voltage regulator is provided to regulate required amount of voltage to the DC load.

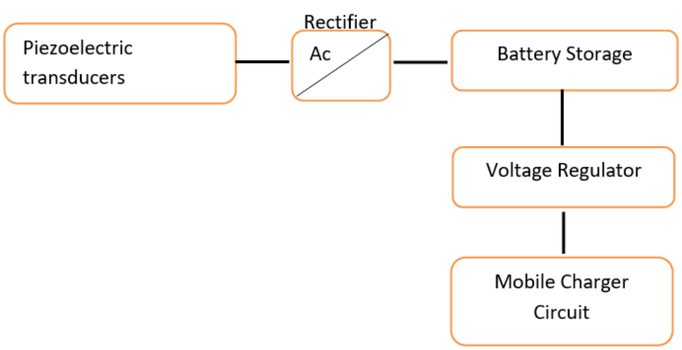

Fig 2: Detailed block diagram of the entire process.

A piezoelectric sensor is a device that uses the piezoelectric effect to measure pressure, acceleration, strain or force by converting them to an electrical signal. They are used for quality assurance, process control and for research and development in many different industries. It has been successfully used in various applications, such as in medical, aerospace, nuclear instrumentation, and as a pressure sensor in the touch pads of mobile phones. In the automotive industry, piezoelectric elements are used to monitor combustion when developing internal combustion engines. Figure 3 presents a piezoelectric crystal.

Fig 3: Piezoelectric crystal

Piezo generation is a renewable energy approach used to harvest electrical energy by a sensing and converting device called piezo sensor/ piezo buzzer. Figure 4 shows the basis of piezoelectric effect. It creates pressure energy on a crystalline material through Quartz crystal to generate electricity [8]. The characterization of piezoelectric sensor was carried out in the laboratory. People with weights vary between 40 kg and 75 kg were made to walk on the piezo tile to test the voltage generating capacity of the Piezo tile. The relation between the weight of the person and voltage generated was established. The characterization procedure adopted was to enable easy comparison with similar works. Thus, maximum voltage of 15V is generated across the tile when a weight of 75 kg is applied on the tile. In the hardware setup, a tile is made from piezo material. The voltage generated across a piezo is predominantly AC voltage. Thus there is need for a rectifier and filter circuit in order to convert into DC.

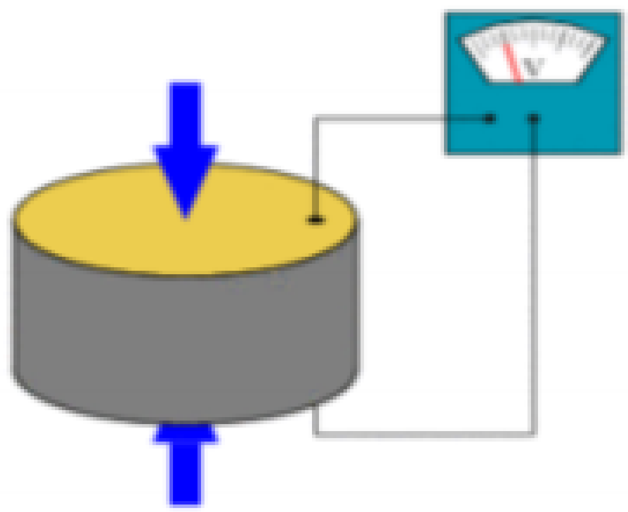

Fig 4: Piezoelectric Sensor Testing [1]

Refering to Figure 1, the voltage regulator, IC 7812 was used to supply a stable voltage (12V) to the load. When a force is applied on piezo material, a charge is generated across it. Thus, equations governing piezoelectricity are developed. A piezoelectric material develops an internal electric field when strained. On the contrary, a piezoelectric material experiences strain when an electrical field is applied to it. These reactions, electrical field and mechanical behavior, can be in either direction. Generally, mechanical parameters are strain S and stress T while for electrical quantities, either polarization or electric flux density D can be variables selected as boundary conditions [9]. These are given in Equations (1) and (2) [10].

$$S = s_E T + d_2 E \quad (1)$$

$$D = d_1 T + \varepsilon_T E \quad (2)$$

Where:
D = electric displacement in C/m^2
d_1 = piezoelectric charge coefficients for the direct piezoelectric effect
d_2 = piezoelectric charge coefficients for the converse piezoelectric effect
T= mechanical stress
ϵ_T = permittivity at constant stress
E= electric field
S= mechanical strain
sE = mechanical compliance
Eqn, (1) shows that part of an electrical field applied to the material is converted into mechanical stress. Similarly in Eqn (2) part of a mechanical strain applied to the material is converted into electrical field. One could notice that in the absence of electric field E**,** the Eqn, (1) becomes S= $S_E T$ which is essentially Hooke's Law; likewise the absence of mechanical stress, Eqn. (2) reduces ($D=\epsilon_T E$ only) describing the electrical behavior of the material. Also, for most materials d_1 and d_2 are nearly equal [10]. Assuming the efficiency of the system approaches100%, then it is assumed that Eqn. (3) holds

$$P_{in} = P_{out} \quad (3)$$

Where: P_{in}=Input mechanical power
P_{out}= Output Electrical power

$$P_{in} = Fv \quad (4)$$

$$P_{out} = IV \quad (5)$$

Where: F=Input mechanical Force in Newton
v= velocity drift in meter per sec
I= current output
V= voltage output
But

$$v = \frac{dx}{dt} \quad (6)$$

$$I = \frac{dq}{dt} \quad (7)$$

$$F\frac{dx}{dt} = V\frac{dq}{dt} \Rightarrow Fx = Vq = Dx \quad (8)$$

Use Eqn. (8) in Eqn. (2) with $D = \frac{q}{x^2}$
where: q is electronic charge in coulomb and x is the drift, in meter.

$$D = \frac{q}{x^2} = d_1 T + \varepsilon_T E \Rightarrow \frac{F}{V} = d_1 T + \varepsilon_T E \Rightarrow V = \frac{F}{x(d_1 T + \varepsilon_T E)} \quad (9)$$

$$\therefore V = \frac{F}{x(d_1 T + \varepsilon_T E)} = kF \quad (10)$$

Where:

$$k = \frac{1}{x(d_1 T + \epsilon_T E)}$$

Eqn. (10) relates the voltage (V) generated by piezoelectric material with the applied force, F and was compared with experimental results. It was found to be highly correlated.
Other design considerations are presented. In this work, only one tile setup is used, connecting piezo in series, then series connections are connected in parallel. Thus when piezoelectric discs are connected in series and its equivalent peak-to-peak voltage becomes NV. The n denotes numbers of cell in series and V is piezo-volt. The piezo element serves as the generator which feeds two 3.7V rechargeable batteries used for storage after generation. Figure 5 shows the circuit diagram described as follow: A 22uF/60Vcapacitor was used for removing ripples from the voltage waveform. The voltage obtained across the capacitor is the output voltage which is applied to a load by the use of a switch. The generation unit comprises of about 16 piezoelectric crystals connected via a series-parallel network. These crystals are all embedded within a 25mmx18mmx3mm rubber tile so as to create a surface on which force can be applied to the crystals. Force was applied by walking and could either be achieved sitting or even moving vehicles. On the other hand, the harvesting unit which helps to collect the generated energy and convert it into useable energy consists of a bridge rectifier, a smoothing capacitor and a variable voltage regulator while the charging unit consists of voltage doubler circuit and a load. This procedure has already be highlighted in the block diagram (refer to Figure 1).
The harvesting unit comprises principally of 16 piezo crystals connected in series-parallel combination. In a piezoelectric crystal, the positive and negative charges are separated, but symmetrically distributed which makes the crystal electrically neutral. Plate I shows the physical piezo-crystals interconnected. The connection was such that each row had four (4) number piezo crystals connected in parallel to improve

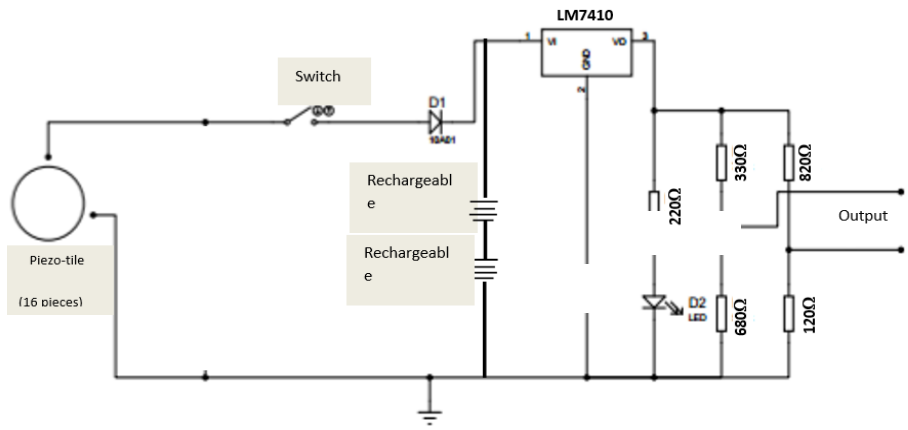

Fig 5: The Circuit Diagram (11)

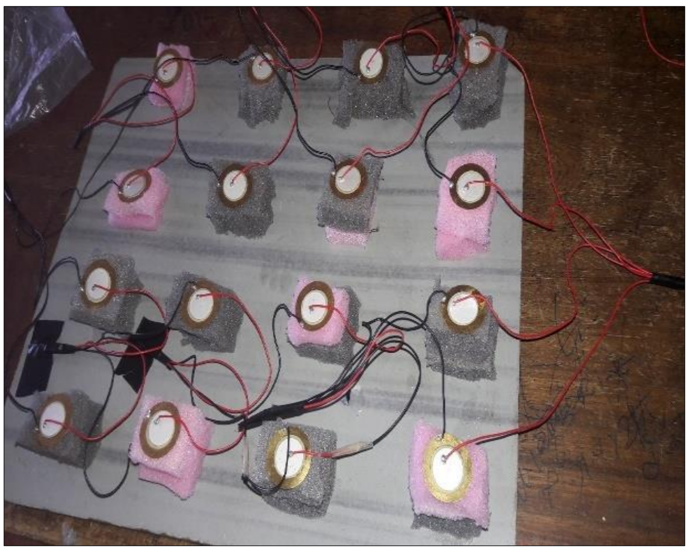

Plate 1: Piezo Electric Series-Parallel Combination

Current level. Four of such rows were then connected in series so as to improve the voltage. In order to prevent damage on the crystal (since varying forces of high degree will be applied on the tile), polystyrene or Styrofoam was cut into rectangular shapes and placed above and below each crystal. Each of this sides form an electric dipole and dipoles near each other tends to be aligned in regions called “Weiss domain”. The domains are usually randomly oriented, but can be aligned during poling, a process by which a strong electric field is applied across the material usually at elevated temperatures. When a mechanical stress is applied, this symmetry is disturbed and the charge symmetry generates a voltage across the material. In converse piezoelectric effect, application of an electric field creates mechanical deformation in the crystal.

The most common application of piezo crystals generating a potential is similar to the electric cigarette lighter which by mere pressing the button of the lighter causes a spring-loaded hammer to hit a piezoelectric crystal to produce a sufficiently high voltage and thus the electric current that flows across a small spark gap, releasing heat and finally igniting the gas. Such substances like quartz can generate potential differences of thousands of volts through direct piezo electric effect.

3. Results and Analysis

Testing was done on every component/section that makes up this entire work to ensure proper and satisfactory operation. A digital multimeter was used to test every single LED used before they are being soldered on the Vero board.

3.1. Measurement of force against voltage

Experiment was carried out by subjecting the piezo tile to stress/strain obtained from different weight samples. Plate II shows the waveform obtained from the piezo tile when force was applied to it from a person weighed to be 65kg.

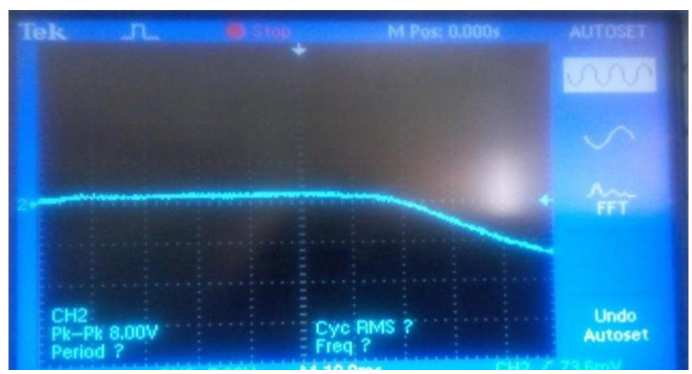

Plate 2: Waveform showing voltage obtained from the piezo tile

3.2. Regression analysis of Piezo-volt

People with weights between 40 and 75kg applied forces, repeatedly at least thrice for each weight, and thus produced potential energy. And the results were tabled in Table 1. Table 2 is the summary of model fitting which yielded $V = 0.142F + 2.40$ at the regression coefficient of 0.9. The plot of linear regression model is shown in Figure 6.

Table 1: Force against voltage Generated

Experimental No.	Weight(kg)	Average Voltage Generated (V)
1.	44	9.10
2.	50	9.26
3.	63	10.38
4.	68	11.02
5.	70	12.54
6.	73	13.68

Table 2: Linear Regression for Piezo-volt: Y = A + B * X

Parameter	Value	Error	
A	2.39751	2.07892	
B	0.1402	0.03339	
R	SD	N	P
0.90282	0.87541	6	0.01371

Due to limited samples, only six (6) samples were observed; weights varied between 44 and 73kg. Table 1 clearly shows the maximum peak-to-peak voltage generated per weight taking a scale of 5V per division on the oscilloscope (Plate II) was 14V at 73 kg. Also, when the data is fitted using regression analysis, the graph shows a linear relationship between the force (weight) and the voltage generated as derived in preceeding section (Eqn. 10).

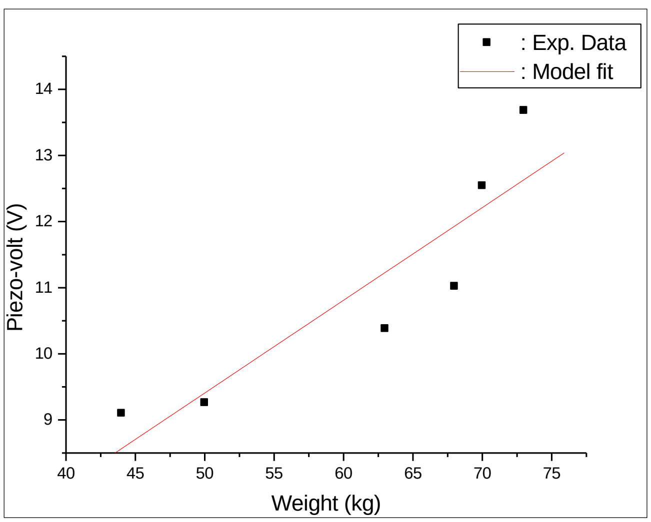

Fig 6: Linear Fit Model of Piezo-volt against weight

4. Conclusion

The aim of the research is to design and implement a piezo-tile system capable of generating power from footsteps used to charge a 5V mobile phone. Having realized the work according to the objectives as it was found working properly with relatively cheap components employed in its realization, the aim of the project can be said to be achieved. It is recommended as a possibility in furtherance of this research to generate electrical energy from unwanted vibrations or simply sound pollutions of gasoline generators used in commercial and residential areas during power outages which is causing global warming but now could be managed based on this work and the energy harvested to generate piezo-energy. Other piezo-sources include vibration from bike rides, travelling in conventional trains and moving vehicle and so on thereby effectively turning all motive energy into an alternative source of electricity generation by the use of piezo sensors.

5. Acknowledgements

Appreciation goes to Late Alhaji Sani Sulenjebu whose memoir remains indelible.

6. References

1. Adhitha A, Vignesh K, Manikandan M. Proposed Method of Foot Step Power Generation Using Piezo Electric Sensor. International Advanced Research Journal in Science, Engineering and Technology. 2015; 2(4):25.
2. Aneja B. Power floor generating energy by walking.
3. Hossain SM, Uddin MN. Energy harvesting from human foot movement. International Journal of Ambient Energy, 2018, p. 1-6.
4. Veena RM, Reddy BH, Shyni S. Maximum energy harvesting from electromagnetic micro generators by footsteps using photo sensor. In 2016 International Conference on Computation of Power, Energy Information and Commuincation (ICCPEIC), 2016. IEEE.
5. Chowdhury DK. Energy Harvesting Mechanism for Network/Device. In Proceedings of conference on Advancement in Computation, Communication and Electronics Paradigm (ACCEP-2019), 2019.
6. Mahalakshmi P, Kalaiselvi S. Energy harvesting from human body using thermoelectric generator. International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering. 2014; 3:5.
7. Abubakar Aliyu Sadiq, JOD Ibrahim Khalil Adam. Current status and future prospects of renewable energy in Nigeria Renewable and Sustainable Energy Reviews. 2015; 48:338-346.
8. Garimella RC, Sastry V, Mohiuddin MS, Piezo-Gen-An Approach to Generate Electricity from Vibrations. Procedia Earth and Planetary Science. 2015; 11:445-456.
9. Ikeda T. Fundamentals of piezoelectricity. Oxford university press, 1996.
10. Ledoux A. Theory of piezoelectric materials and their applications in civil engineering, Massachusetts Institute of Technology, 2011.
11. Sulen-Jebu HS. Footstep energy generation using principle of piezoelectricity, B. Eng. thesis, Faculty of Engineering, Abubakar Tafawa Balewa University, Bauchi (Unpublished), 2019.