

A Study on Piezoelectric Elements and Its Utility in Designing of Electronic Scale

Nilotpal Manna

Department of Electronics and Instrumentation Engineering
JIS College of Engineering, Kalyani, Nadia – 741235, India
email: nmanna324@gmail.com

ABSTRACT

All the electrical or electronic equipment need electrical power supply to operate. Most of these equipments are powered by conventional electricity resources. Conventional energy resource in form of electricity is most economic and cost effective. However this may not be suitable for some applications like portable instruments or the equipments used at remote areas. Therefore there is always search for alternate energy sources and solar energy, biogas, windmill etc. are the results of such searches. They may not be cost effective and there are several disadvantages in these sources. Piezoelectric generator (PEG) is one type of non-conventional energy source that can convert mechanical energy to electrical energy. Though their energy conversion is very low, but they may be used in some typical applications of portable and low power consuming devices. In this paper some investigation has been made how energy can be extracted from piezoelectric generators and efficiency can be improved which is applied as the power source to operate an Electronic Scale.

Keywords: Piezoelectricity, Piezoelectric generators, Transversal, Shear, Display driver.

1. INTRODUCTION

Any type of electronic or electrical or electromechanical equipment requires electricity to operate. Most of them are powered by conventional source of electricity, where generation of electricity is cost effective. But conventional electrical energy may not be suitable for some applications like portable instruments or equipments used in remote areas. Scientists are always looking for alternate source of energy which should be cost effective as well as efficient in operation.

Piezoelectricity is one such type of source of non-conventional energy where electricity is generated from mechanical vibration. Mechanical vibration is observed in daily life and can be generated whenever necessary by individuals. Energy from mechanical vibration can conceivably be obtained from piezoelectric generators (PEG). Therefore PEGs have recently regained interest in the power generation field for portable and low power consuming devices. The merit of applying PEG's to these devices is that they can reduce the battery weight and possibly make the device self-powered by harvesting mechanical energy. However energy conversion from piezoelectric elements is normally very low. To maximize the advantages of piezoelectricity and to optimize its electrical energy production, the electro-mechanical characteristics of piezoelectric materials must be revisited.

Electronic scale or electronic weighing machine is one of the electronic apparatus which has enormous commercial utility or otherwise. This requires low power and with the advent of technology its power consumption has been reduced drastically. In this paper, investigations has been made for different possible configurations of piezoelectric energy generators, with mathematical modeling that result in relationships between applied force (or pressure) and generated electrical energy. This is followed by the analysis to determine the factors that lead to maximum electrical energy generation in relation to a given volume of material or applied mechanical force, pressure, or stress. An analysis of electrical characteristics is made to enhance the power output and efficiency. Finally the design idea of an Electronic Scale has been provided which is powered by the energy generated by piezoelectric elements.

2. BACKGROUND

As a word described by itself, Piezo means pressure, while electric refers to electricity. When crystals are pressurized, an electric field is generated. The piezoelectric effect was first discovered long before by Pierre and Jacques Curie, where they observed the presence of electricity with the application of pressure on the crystals. This is called the piezoelectric effect. The electric field generated by piezoelectric effect is quite small and not very useful until the LiTiBa ceramic was found. After the introduction of the LiTiBa ceramic, the piezoelectricity performance was increased and widely used as an electric device. One of the most common areas is resonators.

Piezoelectric material works both ways. The electric power can be used to generate force or deflection and also, deflection or force can generate electric power. With a usual piezoelectric ceramic, the deflection with an electrical energy is almost invisible to the naked eye. To increase the deflection, a stacked device, or bender device, is used. In the sensor application, conventional diaphragm designs or sometimes spring mass damper designs are used. They are only used to measure the voltage generation.

Until recently, the piezoelectric generator (PEG) was not popular as a power generator because of its small power generation. Modern electrical devices are getting smaller and require smaller amounts of electrical energy. With current technology, the power requirement for low power microprocessors is only about 1 mW, which is possible to be delivered by PEGs. Unfortunately, design problems still remain.

3. PRINCIPLE OF OPERATION OF PIEZO-ELEMENTS

Piezoelectricity is the electric charge that accumulates in certain solid materials (notably crystals, certain ceramics, and biological matter such as bone, DNA and various proteins) in response to applied mechanical stress. The word piezoelectricity means electricity resulting from pressure. In these materials the centers of the negative and positive charges of each molecule coincide, and the external effects of the charges are reciprocally cancelled. As a result, an electrically neutral molecule appears as in figure 1.

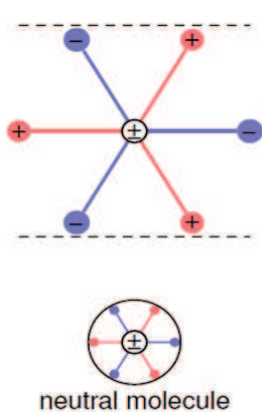


Figure 1: Without Force

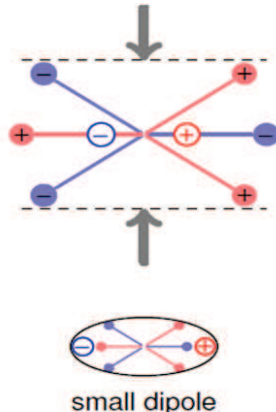


Figure 2: With Force

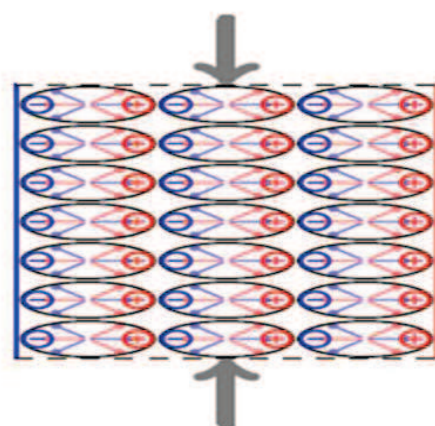


Figure 3: Redistribution of Dipoles

With the application of external force the internal structure of material's surface is deformed, resulting in the separation of the positive and negative centers of the molecules and thus little dipoles are generated. It is illustrated in figure 2. The material is polarized as a distribution of a linked charge appears in the material's surfaces. The facing poles inside the material are mutually cancelled. The polarization generates an electric field from the material's deformation as shown in figure 3, which can be utilized in several applications.

Depending on the way a piezoelectric material is cut, three main types of operations can be distinguished: (i) Transversal, (ii) Longitudinal and (iii) Shear. A gallium phosphate crystal is shown with different modes (arrows indicate the direction where the load is applied). Charges are generated on both sides of the element. The positive charges on the front side are accompanied by negative charges on the back.

3.1 Transverse effect

A force is applied along a neutral axis and the charges are generated along the d_{11} direction as in figure 4. The amount of charge depends on the geometrical dimensions of the respective piezoelectric element. The charge generated is:

$$C_y = -d_{11}F_y b/a$$

where a is the dimension in line with the neutral axis and b is in line with the charge generating axis, d_{11} is piezoelectric coefficient and F_y is applied force in y -direction.

3.2 Longitudinal effect

The amount of charges produced is strictly proportional to the applied force and is independent of size and shape of the piezoelectric element. Using several elements that are mechanically in series and electrically in parallel is the only way to increase the charge output. The resulting charge is:

$$C_x = d_{11}F_x n$$

where d_{11} is piezoelectric coefficient [pC/N] F_x is applied Force in x -direction and n is the number of elements. Figure5 illustrates the longitudinal effect.

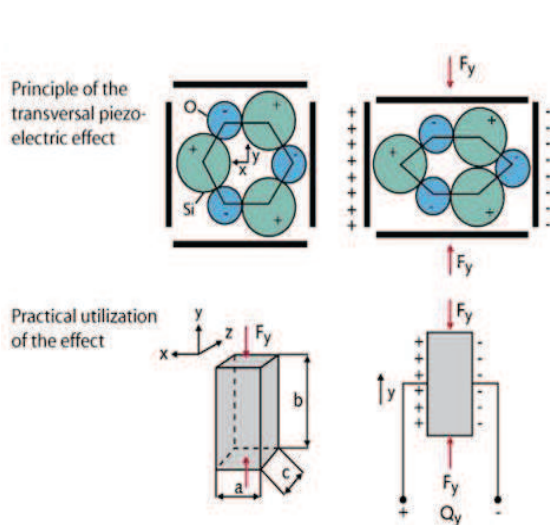


Figure 4: Transversal effect

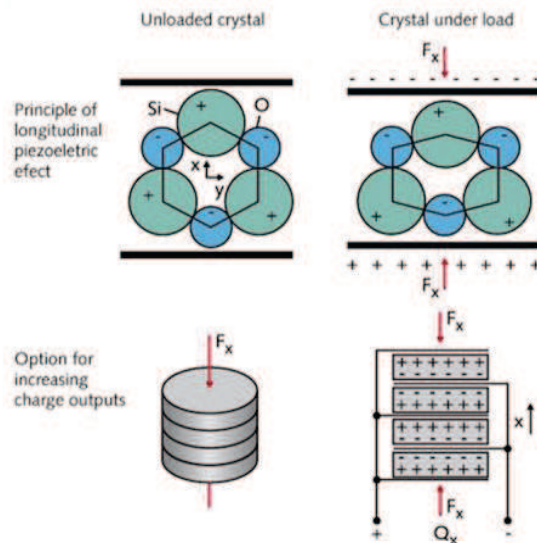


Figure 5: Longitudinal effect

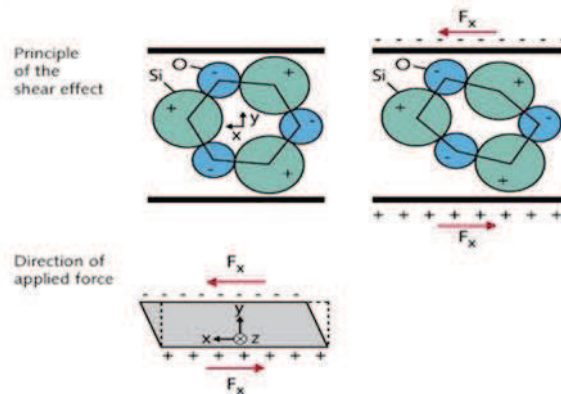


Figure 6: Shear effect

3.3 Shear effect

Again, the charges produced are strictly proportional to the applied forces and are independent of the element's size and shape. It is illustrated at figure 6. For n elements mechanically in series and electrically in parallel the charge is:

$$Q_x = 2d_{11}F_x n$$

4. POWER GENERATION

The voltage and power generation by piezo-elements is not very high, though instantaneous power generated from piezo with application of vibration or mechanical strain is moderate. To extract power, the piezo output voltage is rectified and then placed across a capacitive load to provide smooth DC voltage as shown in the figure 7.

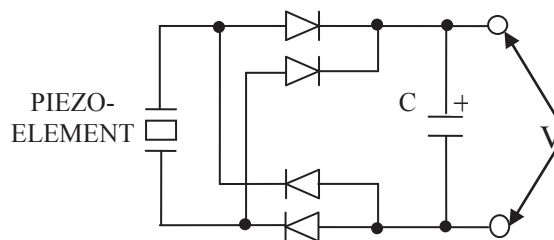


Figure 7: Power extraction circuit

The capacitor value is to be chosen using the following equation for average power, where C is the capacitance in Farads, V is the open circuit voltage piezo, and Δt is a reasonable time interval (~ 10 seconds).

$$P_{av} = \frac{1}{2} \frac{CV^2}{\Delta t} \quad \text{and} \quad C = \frac{2P_{av}\Delta t}{V^2}$$

Electronic circuits generally operate at the power supply of $\pm 3V$ to $\pm 15V$. Therefore, for application of electricity generated from piezoelectric generators to the low power electronic circuits, it is required that the generated voltage level is to be around 3V and this voltage is to be sustained for 15 to 20 sec for processing and display after the removal of mechanical stress. A study has been presented here in this respect where the piezo material is chosen as FT-20T-6.8E Piezo disc which is commercially available.

5. EXPERIMENTAL STUDY AND ANALYSIS ON PIEZO-ELEMENTS

The study on piezo-material has been performed to determine the amount of voltage or power generated with respect to time. One commercially available piezo-material FT-20T-6.8E is placed as shown in the circuit of figure 7. With the output capacitor as 1000 MFD, the voltage versus time observation is noted at table 1. It was observed that voltage output initially increased with the application of mechanical stress but became steady at 1750 mV. To increase the output voltage two piezo elements, each followed by bridge rectifier, are kept in series with similar capacitive load of 1000 MFD. The output voltage became steady at 2150 mV with almost similar rise time. Output voltage is further increased to 2760 mV and 3800 mV, resulted by respectively three and four piezo elements are in series with output capacitance of 1000 MFD. All the results are tabulated at table 1. The results are further presented in graphical form at figure 8.

These results clearly indicate that the steady output voltage is obtained by using multiple numbers of piezo elements in series. It is to be noted that each piezo element is followed by bridge rectifier.

However these observations were obtained at no load condition. To check the performance at loaded condition, four piezo elements are placed in series (each piezo element is followed by bridge rectifier) with capacitor of 1000MFD and 1 K Ω at output, which is tabulated at table 2. It is noted that output voltage became steady at 3000 mV.

Further observation was made to see the effect of output capacitance. Capacitance value is increased to 2200 MFD. There is marginal improvement of steady output voltage as noted at table 2. However advantage of using higher capacitance is that the voltage output remains steady for longer time after removal of mechanical stress. Both the observations are presented at figure 9 in graphical form.

Table 1: Voltage generation by different numbers of piezo-elements in respect of time

	Time (ms)	Voltage (mV) One Piezo	Voltage (mV) Two Piezos	Voltage (mV) Three Piezos	Voltage (mV) Four Piezos
1	100	125	150	215	370
2	200	220	220	395	495
3	300	300	300	500	600
4	400	395	400	580	695
5	500	490	500	670	800
6	700	600	620	810	1070
7	900	715	800	1000	1300
8	1000	810	920	1180	1400
9	1200	920	1040	1300	1600
10	1500	1000	1260	1450	2000
11	1800	1080	1420	1600	2320
12	2000	1140	1500	1780	2550
13	2200	1200	1570	1900	2790
14	2500	1260	1720	2000	3020
15	2800	1380	1790	2080	3200
16	3000	1480	1820	2130	3300
17	3200	1530	1850	2215	3400
18	3500	1600	1880	2310	3500
19	3800	1650	1920	2400	3600
20	4000	1700	2045	2480	3700
21	4500	1750	2090	2590	3800
22	5000	1750	2150	2760	3800
23	5500	1750	2150	2760	3800
24	6000	1750	2150	2760	3800

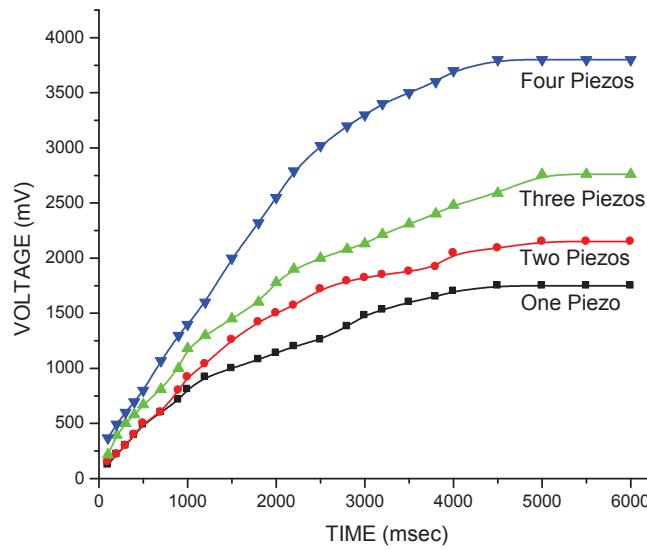


Figure 8: Voltage vs Time performances of Piezo-elements

Table 2: Voltage generated by four piezo-elements with variation of output capacitance

	Time (ms)	Voltage (mV) with C=1000MF	Voltage (mV) with C=2200MF
1	200	80	80
2	400	170	180
3	600	290	295
4	800	415	420
5	1000	550	560
6	1200	730	745
7	1500	1040	1050
8	1800	1250	1260
9	2000	1410	1490
10	2200	1600	1700
11	2500	1870	1920
12	2800	2100	2200
13	3000	2260	2480
14	3200	2460	2650
15	3500	2790	2955
16	3800	2900	3240
17	4000	3000	3300
18	4500	3000	3300
19	5000	3000	3300

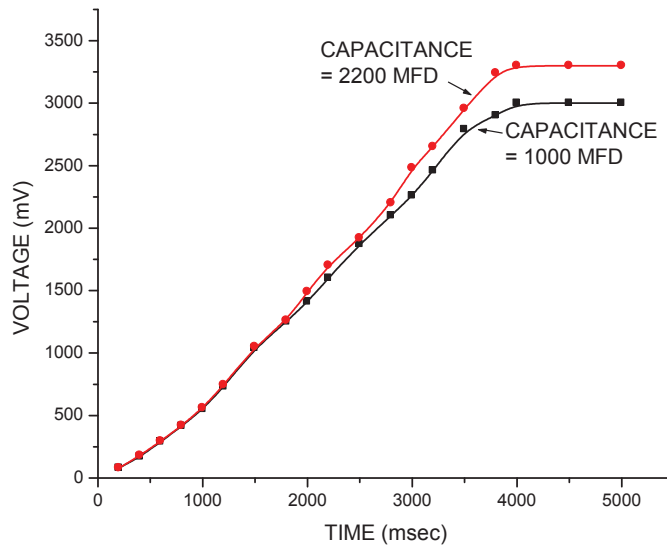


Figure 9: Voltage vs Time with four piezos and 1K load with different output capacitances

It is evident from above experimental study that piezo elements can deliver desired power supply for low voltage electronic applications. To improve current/power requirement, two or three sets of piezo element can be used in parallel, where each set of piezos comprised of four piezo elements with bridge rectifiers in series as illustrated at figure 10. The above experimental study on piezo-electricity generation is applied as circuit power supply of electronic scale.

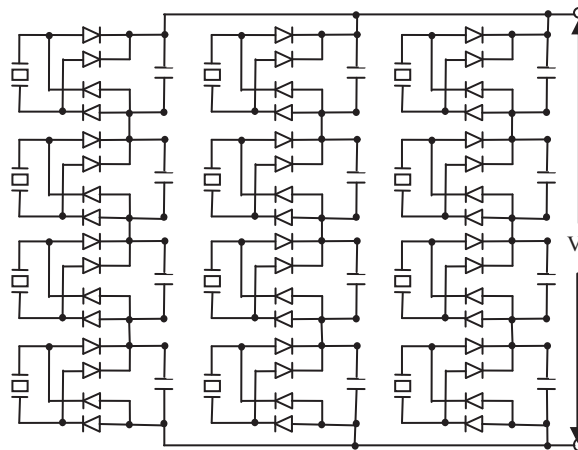


Figure 10: Piezoelectric power generation

6. DESIGN IDEA OF ELECTRONIC SCALE

The electronic scale developed in laboratory is meant for low cost and low weight measurement up to 1Kg. Load cell strain gauges are used as sensor elements that are mounted on a weighing platform. According to the weight of material, the weight sensing elements strain gauges, when biased, convert weight to electrical signal. The sensor output signal is passed through a signal conditioner circuit followed by an amplifier circuit and finally fed to the display unit. The schematic diagram is given at the figure 11.

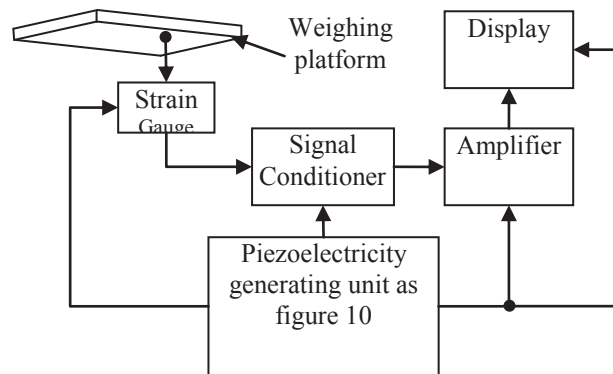


Figure 11: Schematic Diagram of an electronic scale

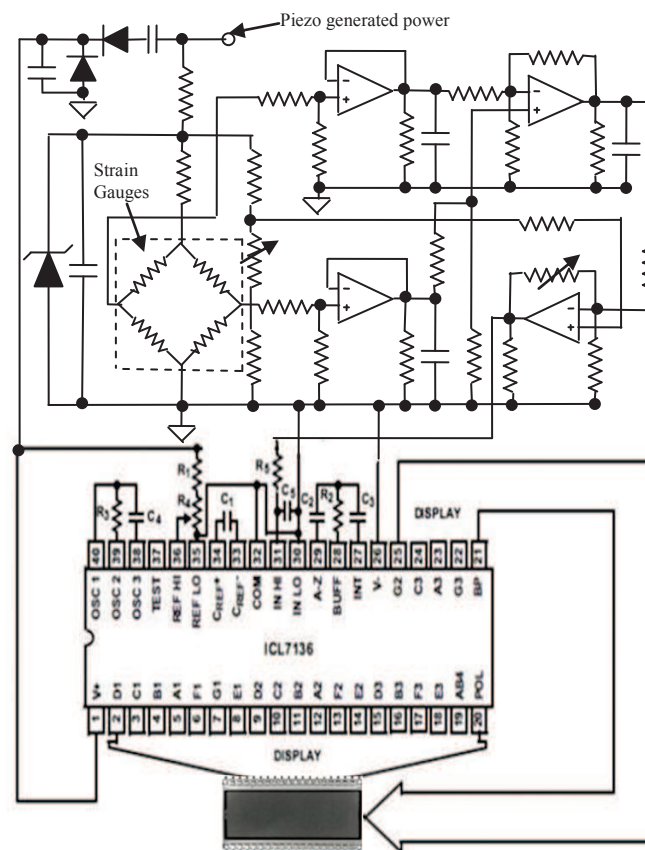


Figure 12: Circuit Diagram of Electronic Scale

The complete circuit diagram of the electronic scale is presented at figure 12. Load cell strain gauges are mounted at the weighing platform such that any load kept on the platform yields mechanical stress resulting in changes of resistances of the strain gauges. Strain gauges are placed in Wheatson bridge configuration. When any load is placed on the platform, the resistances of the arms of Wheatson bridge are changed to create an unbalanced condition, resulting in difference in voltage. The signal conditioning of voltage difference from wheatson bridge is accomplished by passing through unity gain amplifiers followed a differential amplifier. The output of differential amplifier is fed to another stage of amplifier. Zero and Span adjustments are provided by variable resistances. Quad operational amplifier LM 324 may be employed for above operation. Zenner diode of 2.7V is used for biasing the Wheatson bridge to stabilize and to avoid any minor fluctuation in the supply voltage which is generated by piezo-elements. The amplifier output is equivalent to the load kept at the weighing platform which is analog in nature. This amplified signal is fed to an integrated circuit ICL7136 that performs the tasks of 3½ digit analog to digital

conversion and LCD display driver. The outputs of LCD driver are connected to the LCD display unit. LCD display has the advantage of low power consumption, which is necessary for piezoelectricity driven equipments. The operation amplifiers are powered by the piezoelectricity as discussed above. However to meet the supply voltage requirement of ICL7136, a voltage doubler circuit is employed. The scheme as described above has been experimentally tried in the laboratory producing satisfactory results with good accuracy. The hardware set up is shown at figure 13.

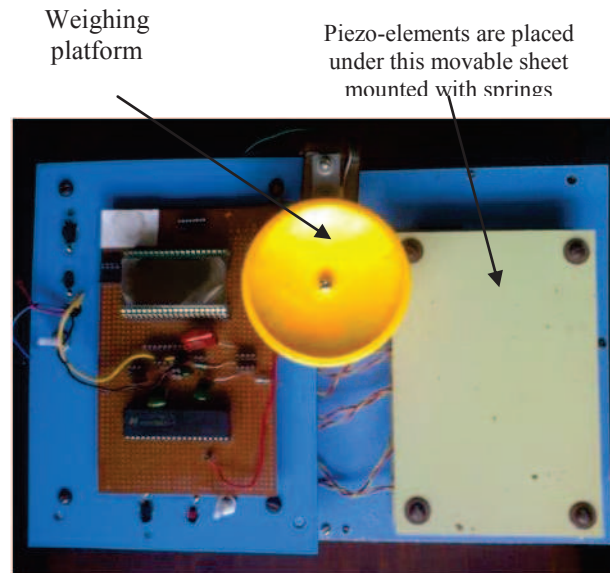


Figure 13: Hardware set up

7. DISCUSSION AND CONCLUSION

As observed from the experimental study above, the piezoelectric elements can deliver a good amount of power that may be useful for low power electronic devices or portable instruments. It is proved at the successful implementation of low power weighing machine in the laboratory. The hardware structure for energy extraction from piezo-elements is done in prototype by placing the elements in between two non-metallic sheets with spring arrangement. The mechanical stress is achieved by vibrating one the sheets by hand. However this arrangement may be improvised to generate more mechanical vibration with little effort. Though this laboratory model is intended for weighing up to 1Kg, the same circuit idea can be applied for higher weight measurement by selecting proper load cell and calibration.

Piezoelectric elements offer a unique set of capabilities- inherent temperature stability, the amplitude range and the signal quality. This experimental study was made on commercially available piezo-elements. However there is lot of researches to improve the performance of piezoelectric elements and manufacturers offer wide range piezoelectric elements of higher performance. Cadmium Sulphide, Gallium Arsenide, Tellurium Dioxide, Aluminum Nitride etc. are the few among high performance piezoelectric materials. Integrated circuits are also available for efficient energy harvesting from piezoelectric materials. Using proper mechanism piezoelectric elements can be used as replacement of battery. However one disadvantage in above design idea is that continuous display is not possible as the piezoelectric power decreases with the withdrawal of mechanical stress. With proper selection of capacitance at piezoelectric power generation circuit, the display time duration may be adjusted so that a person can read.

Piezoelectric power generators (PEG) have many advantages over other conversion methods.. Because of their simplicity, PEG's can even be made small enough to fit inside of micro electromechanical systems (MEMS). Another advantage is that the lifetime of the system is almost unlimited if the applied force and external temperature are within the operational range. Unlike the power generation methods that rely on heat conversion, a PEG presents no problems such as heat isolation. In addition, much of energy is being lost different vibrational environments like running of machineries, moving vehicles, moving staircases etc. PEGs can be employed to extract energy from these nonconventional sources. Even with these advantages, PEGs have been neglected for power generation because of the small electrical output.

8. REFERENCES

- [1] ANSI/IEEE, IEEE standard on piezoelectricity. IEEE Standard 176-1987 (1987).
- [2] L.F. Brown, Design consideration for piezoelectric polymer ultrasound transducers. IEEE Trans. Ultrason. Ferroelectr. Freq. Control 47, 1377–1396 (2000).
- [3] S.A. Morris, C.G. Hutchens, Implementation of Mason's model on circuit analysis programs. IEEE Trans. Ultrason. Ferroelectr. Freq. Control 33, 295–298 (1986).
- [4] W.M. Leach, Controlled-source analogous circuits and SPICE models for piezoelectric transducers. IEEE Trans. Ultrason. Ferroelectr. Freq. Control 41, 60–66 (1994).
- [5] A. Püttmer, P. Hauptmann, R. Lucklum, O. Krause, B. Henning, SPICE models for lossy piezoceramics transducers. IEEE Trans. Ultrason. Ferroelectr. Freq. Control 44, 60–66 (1997).
- [6] K.W. Kwok, H.L.W. Chan, C.L. Choy, Evaluation of the material parameters of piezoelectric materials by various methods. IEEE Trans. Ultrason. Ferroelectr. Freq. Control 44, 733–742 (1997).
- [7] A.M. Vinogradov, V.H. Schmidt, G.F. Tuthill, G.W. Bohannon, Damping and electromechanical energy losses in the piezoelectric polymer PVDF. Mech. Mater. 36, 1007–1016 (2004)
- [8] S. Sherit, H.D. Wiederick, B.K. Mukherjee, Non-iterative evaluation of the real and imaginary material constants of piezoelectric resonators. Ferroelectrics 134, 111–119 (1992).
- [9] TASI Technical Software Inc. Ontario, Canada (2007). Available at: <http://www.tasitechnical.com>.
- [10] R.S. Dahiya, M. Valle, G. Metta, L. Lorenzelli, S. Pedrotti, Deposition processing and characterization of PVDF-TrFE thin films for sensing applications, in IEEE Sensors: The 7th International Conference on Sensors, Lecce, Italy (2008), pp. 490–493.
- [11] Internet site <http://www.ti.com>.
- [12] Internet site <http://www.intersil.com>.
- [13] Internet site <http://www.linear.com>.
- [14] Internet site <http://mide.com>.
- [15] Performance of PZT-Based Piezoelectric Ceramics, IEEE 1996, pp. 967-970.
- [16] Millman J, Halkias Christos C. *Operational Amplifiers*, McGraw-Hill, ISBN0070446636, 9780070446632.
- [17] Singh K, A thesis on *Study on Solar/Biogas Hybrid Power Generation*. Thapar University.

ACKNOWLEDGEMENT

The Author acknowledges the Technical Education Quality Improvement Program (TEQIP) for the support to precede the publication.

ABOUT THE AUTHOR

Nilotpal Manna obtained B.E. degree in Electronics and Telecommunication Engineering in 1979 from Bengal Engineering College, Sibpore, Kolkata, now renamed as Bengal Engineering and Science University and received M Tech degree in 1981 from Indian Institute of Technology Madras (Chennai). He has wide industrial experience of twenty-two years from semi- government sectors like Instrumentation Ltd, Kota and several private industries like Toshniwal Instruments Manufacturing Pvt Ltd and others. He served mostly in the Research and Development wings and was associated in development of various electronic and communication instruments meant for military application as well as development of analytical instruments. At present he is Head of the Department of Electronics and Instrumentation Engineering of JIS College of Engineering, Kalyani, West Bengal, India. He has several research publications in national and international journals and conferences, and authored four technical books.

E-mail: nmanna324@gmail.com