ENERGY HARVESTED FROM RESPIRATORY EFFORT

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Keywords: Respiratory effort, Energy harvesting, Piezoelectric power converter.

Abstract: Presently, a high cost of some medical equipment is due not only the sophisticated technology, but also because the cost of his maintenance. The electronic devices implanted in the human body are examples for this constant maintenance, requiring sophisticated medical operations. Extra weight and volume addition to the electronic devices are also a disadvantage, limiting the autonomy of such devices. An alternative to replace the batteries as power sources is to obtain the energy from the human body. In this work we present our prototype of Breathing Energy Transducer (BET) for an efficient energy conversion at fixed 2.6V from chest movements during breathing. A series of experiments were performed in order to calculate the power that could be generated from the respiratory effort during normal and deep breathings.

1 INTRODUCTION

Currently, the energy supply for the portable and autonomous equipment comes almost exclusively from the battery. Unfortunately the maintenance of those sources of energy brings disadvantages due to the need for frequent recharging or replacement. In many cases the battery brings extra weight and volume to the electronic equipment, limiting its autonomy. Some possible alternative methods to replace the batteries as power source, or to achieve better maintenance of existing (or smaller) batteries, are the so called Energy Harvesting (EH) methods, i.e. to obtain energy from the environment. For the medical equipment, there is also a possibility to recover and store energy generated by the human body in its usual activities.

This article we explore a possibility to obtain and convert an energy from the chest expansion during the normal and deep breathings. The harvested energy is either converted to a fixed 2.6V value, by an extremely efficient converter developed by our team for this purpose. The low amount of energy harvested from the chest expansion can be enough for the proper functioning of certain systems, e.g. MEMS systems.

2 ENERGY SOURCE

There are several techniques to obtain energy from the environment, either for storage or for direct supplying the electronic consumers. The energy harvesting device generates electrical energy from the environment applying different conversion methods. In an early work, S. W. Angrist calls this conversion a “Direct Energy Conversion” (Angrist, 1971). In the present time the converters are carefully designed for each different source of environmental power. They are expected to have high conversion efficiency, mostly due to the lowest values of energy collected from the environment. Kinetic, thermal and electromagnetic energy are some of the possible examples of energy source.

2.1 Kinetic Energy

This source of energy is one of the most readily available to be converted from the human body. The mechanical deformation of a certain structure and the displacement of a mass are the basic principles of the kinetic energy conversion. Using the principle of piezoelectricity is one method to convert mechanical deformations and movements into

Cavalheiro D., Silva A., Valtchev S., Pamies Teixeira J. and Vassilenko V..
ENERGY HARVESTED FROM RESPIRATORY EFFORT.
DOI: 10.5220/0003876703880392
In *Proceedings of the International Conference on Biomedical Electronics and Devices* (BIODEVICES-2012), pages 388-392
ISBN: 978-989-8425-91-1

electrical energy.

Grate research has been carried out to collect as much energy as possible from the human body. A work done by T. Starner and J. Paradiso presents the actively and passively dissipated energy during the simple human activities(Starner and Paradiso, 2004). One of the most explored energy sources from the human body were the energy generated through the force applied by the foot in a piezoelectric insole during a walk (Kymissis et al., 1998).

Breathing is another possible source of energy. The mechanical energy of the exhaled air can be converted to the electricity. For example, using a special mask with a turbine it possible to generate the mechanical power of approximately 1W (Starner, 1996).

From other side, the mechanical chest movements during breathing can be used as another way to harvest energy. In this process the piezoelectric effect can be used to convert the mechanical strain into electricity. It was estimated that breathing with a mean frequency of the 10 breaths per minute can develop a mechanical power of 0.83W (Starner, 1996).

However, the mechanical energy cannot be converted completely in electricity due to losses in harvesters and the other mechanisms. As a rule, the electronic devices must have extremely high efficiency both in energy conversion (harvestes) and energy consumption (the control circuits). Larger losses in the various components are translated into lower conversion efficiencies. Usually the data presented in the literature consider that the mechanical generator have 50% efficiency; the turbine + generator reach 40% efficiency; the piezoelectric generator have 11% efficiency and the double (including mechanical to mechanical and other) conversion reach 12.5% efficiency (Starner, 1996).

3 POWER EXTRACTED FROM HUMAN BREATH

In the present work were performed a series of experiments in order to analyse the power generated from human respiratory effort. For this purpose we develop a Breath Energy Transducer (BET) working as a piezoelectric generator.

The piezoelectric effect characterizes a class of certain crystalline structures that become electrically polarized when subjected to pressure. The reverse effect is also known, i.e. when electric field is applied to the crystal, its dimensions change according to the applied electric field (inverse piezoelectric effect). Initially, quartz was the most well-known piezoelectric material, but now mostly ceramic materials based in metal-oxide are used due to the lower price.

The piezoelectric generator used to harvest energy from chest expansion, contain one piezoelectric transducer (Breath Energy Transducer), producing electric charge when subjected to compression. The generated voltage in this kind of transducers may be high, but the value of the produced current is (unfortunately) low. Some piezoelectric systems tend to achieve better performance through applying higher frequencies of mechanical vibrations.

3.1 Breath Energy Transducer

The Breath Energy Transducer (BET) is a home-made prototype of piezoelectric generator with sensor composed by Macro Fibers (MFC) that offers high performance, durability and flexibility. It consists of rectangular piezoceramic rods (wires) sandwiched between layers of epoxy polymer, electrodes and polyimide film. The piezoelectric sensor used in this work is the M-1700-P2 (170mm x 7mm), developed for NASA. It presents a capacitance of 91nF, free strain of -670ppm and a blocking force of -42N.

Figure 1: Piezoelectric Breath Energy Transducer.

A BET was attached to a band (Figure 1), which allow it fixing around the chest of a person.

3.2 Respiratory Effort Transducer

For measuring the amplitude of the chest during the breathing was used a commercial respiratory effort transducer SS5LB from BIOPAC©, also fixed around the chest of a person (Figure 2). It measures the respiratory effort and transmits the signal from the chest expansion and contraction. The transducer was applied to determine the depth of the breathing and to calculate the breathing rate. By this measurement it was possible to compare the normal breathing to the deeper one, and to observe the power generated by the harvesting piezoelectric tape.

Figure 2: Respiratory effort transducer SS5LB and its location.

The respiratory effort transducer was connected to the BIOPAC© MP35 measuring system with internal microprocessor to control the data acquisition and recording software BSL Pro.

This measuring unit was necessary for comparing the recorded breathings to the power converted by the piezoelectric Breath Energy Transducer.

4 EXPERIMENTAL RESULTS

The first step on the experimental procedure was to find a correlation between the power consumed by the load resistor, attached to the piezoelectric BET, and the chest expansion while breathing normally and deeply. The relation between the SS5LB sensor signal and the SS5LB extension is shown in Figure 3. Considering that the maximum output of the SS5LB sensor is proportional to the maximum depth of breathing, a relation between the chest expansion (in mm) and the output signal is possible to be achieved for each individual person. This calibration have allowed to find the relation between the chest expansion and sensor extension (in mm), useful for the proper construction of the Breath Energy Transducer.

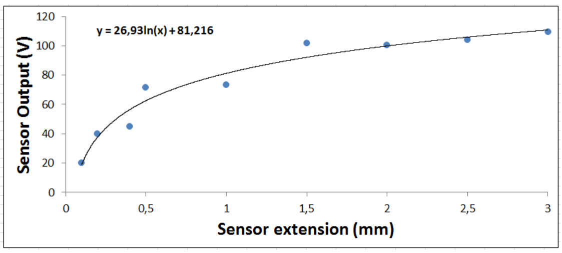

Figure 3: Relation between SS5LB output and SS5LB extension.

The second step was aimed at finding the ideal load for the piezoelectric Breath Energy Transducer. Figure 4 shows the continuous power absorbed during the loads in the range from 1kΩ to 2MΩ.

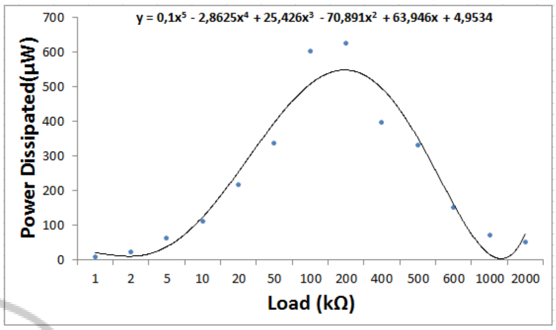

Figure 4: Power produced by the piezoelectric BET at different loads.

As it can be seen from the graphic in the Fig. 4, a maximum of dissipated power is reached with a resistive value of load around 200kΩ, where will continuously dissipating 620µW. This load has been used in the experiments to achieve a relation between the chest expansions and the extracted power values from the Breath Energy Transducer.

The third step consists in finding the relation between the chest expansion, and the power delivered to the load (200kΩ). For this purpose were performed a series of experiments: a healthy person with 1.64m of height and 60kg of weight were asked to perform six normal breathings and six deep breathings. A typical resulting signal in an SS5LB output is given in Figure 5. In this graphic the first six signals are related to normal breathings followed by the next six signals related to deep breathings. As it was expected, the normal breathings give lower SS5LB output signals (peak to peak) than the deep breathings.

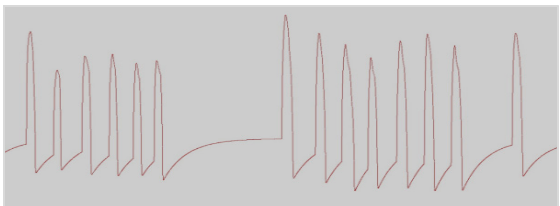

Figure 5: SS5LB output signal, in V(t).

An oscilloscope was used to measure the AC voltage delivered to the load. Resulting graphics of obtained signals for normal and deep breathings are presented in Figure 6 and Figure 7, respectively. From the oscilloscope data were also obtained the RMS voltages, allowing calculates the values for an active power available at the (resistive) consumer. This power is given by equation 1, resulting in

19µW and 50µW for normal and deep breathing, respectively.

$$P = \frac{V_{RMS}^2}{R} \quad (1)$$

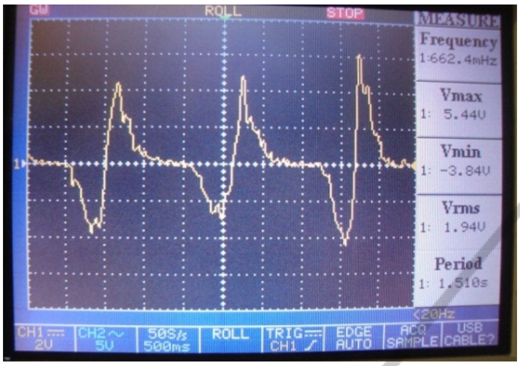

Figure 6: Oscilloscope output signal for normal breathings.

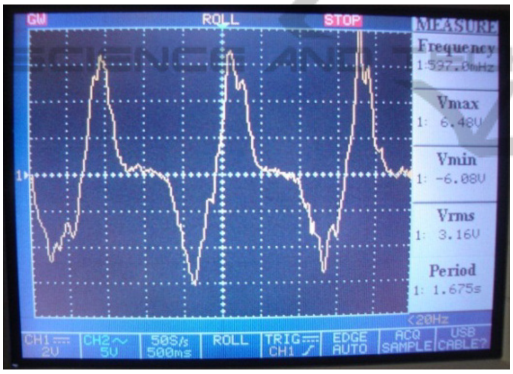

Figure 7: Oscilloscope output signal for deep breathings.

Previously, it was found a relation between the chest expansion in normal and deep breathings, resulting in an expansion between 2 cm and 3.18 cm while breathing normal, and an expansion between 3.54cm and 4.05cm while breathing deeply. With this relation, it is possible to affirm that for a specific person, an expansion of the chest with 4cm can provide an average power of 50µW to any electronic sensor that presents ideal input impedance, around 200kΩ.

An extremely efficient converter from Linear Technology was used to convert the AC signals generated by the generator tape due to the chest expansions. The converter was configured to outputs a value of 2.6V, to a capacitor of 47µF. The experimental results are shown in Figure 8 and Figure 9. In both figures, the yellow signal represents the rectified voltage from the piezoelectric BET, and the blue signal show the output value of the capacitor.

Figure 8: Output value for charging during normal breathing.

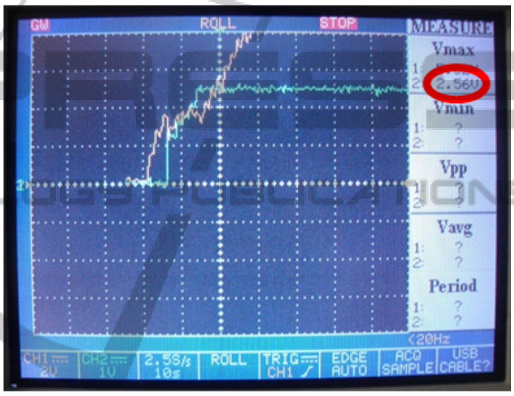

Figure 9: Output value for charging during deep breathing.

As it can easy observe, the normal breathing during around 25 seconds will allow charging the capacitor until 2.5V, while deep breathing will take less time, around 20 seconds. The obtained results for the charging time have a clear correlation with less voltage, and consequently less power, generated during the normal breathing than during the deep one.

5 CONCLUSIONS

The experimental study performed in this work shows that the mechanical movements of the chest during the breathing can be used as an energy source harvested from the human respiratory effort. Obtained results also showed that deep breathing is able to generate almost 3 times more power than normal breathing.

The proposed prototype of piezoelectric Breath Energy Transducer using an efficient converter was able to generate enough power to charge a capacitor of 47µF to a fixed value of 2.6V due to its mechanical deformation caused by respiratory effort movements. This capacitor of 47µF charged until 2.6V could be sufficient as to act as an electric source to any system that presents very low power consumption.

In the future, the output power value of BET can be improved by better adapting of electronic circuits. Another important improvement will be obtained by the optimizing present mechanical construction in order to enable maximum compression in the piezoelectric tape at minimum breathing effort.

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