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► **To cite this version:**

Stephane Carras, Benoit Agnus, Blaise Elysée Guy Ravelo, Blaise Nsom. Experimentation of an Ambient Micro-Energy Harvester Pillow. 2019. hal-02366695

**HAL Id: hal-02366695**

**<https://hal.science/hal-02366695v1>**

Preprint submitted on 16 Nov 2019

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# **Experimentation of an Ambient Micro-Energy Harvester Pillow**

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## **Abstract**

This article is devoted to the feasibility study of mechanical ambient pressure micro-energy harvesting into a useful electrical energy. This mechano-electrical energy transduction is implemented with an innovative concept of Chairs and Armchairs Micro-Energy Harvester (CAMEH). The proposed micro-energy harvester is designed with a textile-based pillow incorporating a piezoelectric. The principle of the micro-energy transduction is described based on a systematic approach. To illustrate the feasibility of the CAMEH concept, a proof of concept (PoC) of micro-energy harvester pillow built with textile structures provided by the company FILIX® has been fabricated. As expected, electrical energy presenting average voltage of about hundreds of millivolts is generated. The present CAMEH concept will be exploited to overcome the issues related to the connected wearables and objects. Several applications are currently being under study notably in the areas of future automotive, aerospace, space, rail and logistics.

*Keywords: Ambient Micro-energy; Chairs and Armchairs Micro-Energy Harvester (CAMEH); Electro-mechanical analysis; Piezoelectric; Proof of concept; Recovery; Textile structure.*

## **1. Introduction**

To meet the needs of the inhabitants, new generations of smart transportations (trains, trams, cars, planes ...) seem unavoidable to solve traffic jams and further issues in all big cities and megalopolis. Nonetheless, incorporating intelligent functions requires the implementation of continuously or permanent connected objects. To ensure the all-time connections, a new generation of power system should be developed. To face up this technical challenge, ambient micro-energy harvester devices have been proposed. Among the ambient micro-energy harvesters, piezoelectric devices performing mechanical energy transductions into electrical energy are currently the most used.

With the emergence of connected portable devices, the development of mechanoelectric transducers, particularly based on the mechanical energy of the movement of the human body, is a promising solution [1-3]. Biomechanical energy harvester technology is revolutionizing connected medicine, for example through the harvester of energy from animal organs [4-5]. Recently, Bionic-Power® has developed an innovative product called PowerWalk® based on foot contact harvester in contact with the ground [6].

In this context, the purpose of this article is to initiate the feasibility of designing piezoelectric mechanical micro-energy harvester textile devices. Recent studies have highlighted the possibility of making actuators based on piezoelectric composite microfibrils [7], composite networks incorporating piezoelectric [8], nanogenerators using PZT nanofibers [9] and a triboelectric generator biopolymer base [10]. Prototypes of textile devices reinforced with thermoplastic structures and incorporating PZT sensors have also been developed [12-13]. In 2014, a research team from the University of Bolton developed a proof of concept laboratory 3D woven piezoelectric sensor recovering mechanical micro-energy. These potentials of design and realization of energy harvester textile structures motivated us to develop innovative solutions to the needs of self-powered devices connected to the means of transport of large cities by imagining “Chairs and Armchairs Micro-Energy Harvester (CAMEH)” seated passengers.

With the textile products of the company FILIX® [14] based in Normandy, a new solution for the recuperation of mechanical micro-energy of chairs and armchairs is being developed within the framework of the regional project FIL HARMONIQUE. This article briefly describes the proof of concept of CAMEH by making a harvester pillow of energy generated by mechanical pressure.

For a better understanding, this article is mainly divided into four main sections. Section 2 introduces the operating principle of the mechanical energy harvester pillow. Section 3 presents the demonstrator based on FILIX® textile products. Section 4 offers a theoretical analysis of analytical deposit with an ideal empirical numerical application of a CAMEH test case. Finally, Section 5 summarizes the article with a conclusion.

## **2. Principle of mechanical pressure energy harvesting with textile pillow**

As introduced in the previous section, the objective of this study is to carry out an empirical feasibility study of the micro-energy harvester of a piezoelectric pillow.

### **2.1 Illustration of the harvesting scenario test case**

Figure 1 illustrates the application context of the CAMEH principle. This principle consists of considering a passenger seated on a chair by exerting a mechanical pressure represented by  $\vec{F}(t)$  as function of time  $t$ . The mechanical energy exerted on the chair can be converted into electrical energy by considering a micro-energy harvester pillow.

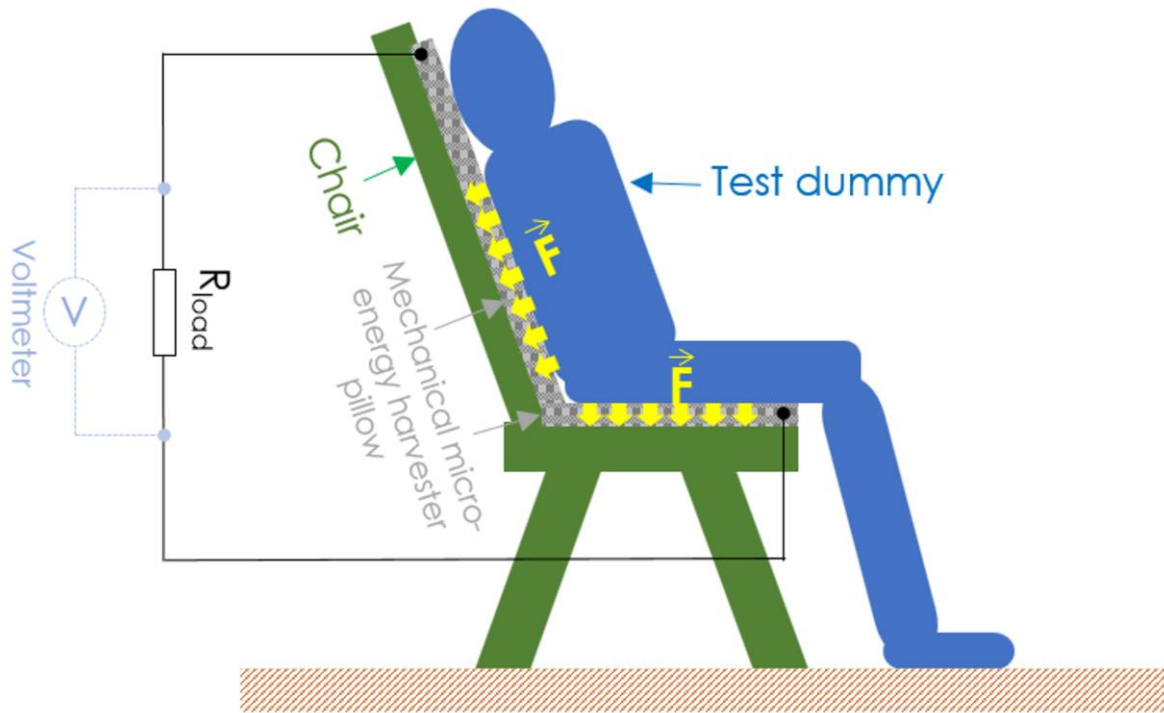


Figure 1: Illustration of the CAMEH operation.

## 2.2 Recall on the piezoelectric analytical modelling

The basic understanding of the CAMEH mechanism depends on the theoretical approach of the piezo effect. To analyse the piezo device functioning, the electromechanical engineers proceed with the Hamilton principle. The principle provides is a powerful tool for solving mechanical problems [15]. This principle enables to transform a physical system into variational problem. The analysis can be done by solving the unknowns as the energy as a function of the time variable  $t$ . Considering a temporal variational system from instant  $t_1$  to instant  $t_2$ , the exploitation of the modified Hamilton principle will lead to the integro-differential relation [15]:

$$\delta \int_{t_1}^{t_2} [E_c(t) - E_p(t) + E_e(t)] dt + \int_{t_1}^{t_2} \delta E(t) dt = 0 \tag{1}$$

with:

- The parameter  $E$  represents the work of the applied external force;
- The parameter  $E_c$  represents the kinetic energy;
- The parameter  $E_p$  represents the potential energy;
- And the parameter  $E_e$  is the electrical energy.

Through this relationship, mathematical models to illustrate the transduction of mechanical force into electrical voltage have been developed [1-13].

### 2.3 Systemic description of the mechanical energy harvester pillow

The concept of the harvester pillow is based on the context of the CAMEH defined previously in Figure 1. The systemic approach of this concept is illustrated by the diagram of Figure 2. Functionally, the pillow is essentially made up of three blocks:

- The input block represents the mechanical pressure  $\vec{F}(t)$  applied to the pillow. The mechanical energy associated with this block depends on the value of the force and the contact surface.
- The output block represents the electrical energy quantity converted via the piezo effect. The main parameters for evaluating this electrical energy are the electrical voltage, the current and the associated active power.
- And the transduction block, it corresponds to the mechano-electric transducer. This block can be expressed analytically with a transfer function integrating the characteristics of the piezoelectric.

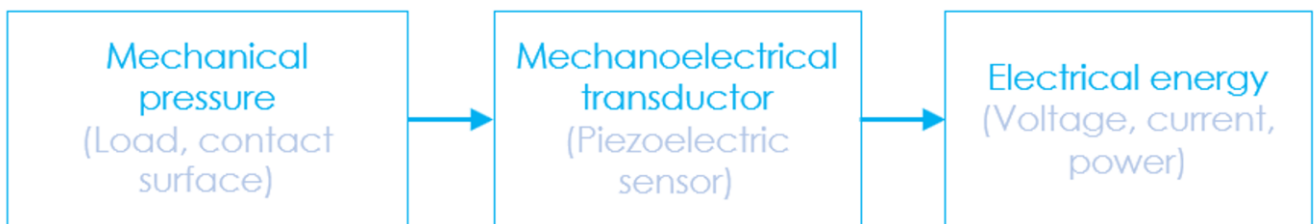


Figure 2: Systemic diagram of the proposed CAMEH principle.

For a more concrete understanding of this CAMEH principle, an experimental analysis will be discussed in the next section.

### **3. Experimental analysis**

The pillow PoC is mainly made of 100% textile materials supplied by the company FILIX® [15]. Figure 3 shows a picture of some coils of wire available for the FIL HARMONIQUE project. In the present study, we used a fully textile conductor wire with a diameter of 0.5 mm to ensure electrical connections.



Figure 3: FILIX® wire spools.

#### **3.1 Pillow PoC description**

Our proof of concept of the harvester pillow has been manufactured in a traditional way to demonstrate the conversion of mechanoelectric energy. Figure 4 shows the photo of the prototype. This demonstrator is mainly composed:



- A circular piezoelectric pellet loosely supplied commercially reference SB\_PEP35mm Electroncomponents. It has a diameter of 3.5 cm and a thickness of 1 mm. It integrates a buzzer operating at the frequency 4.6 kHz.
- Conductive son providing the connection between all the components of the electrical circuit constituted by the mechanical pressure piezo.
- A cotton foam, it serves to protect the piezoelectric and to maintain well its integration in the pillow.
- And a textile fabric cover to pack the whole.



Figure 4: Photo of the mechanoelectrical harvester pillow prototype.

### 3.2 Experimental results

Simple experimental tests under a real-world application condition were made to illustrate the possibility of mechanical energy conversion. The equivalent circuit is composed of the pillow connected to a voltmeter as explained in Figure 5. It is thus possible to visualize in real time the electrical voltage generated by the piezoelectric when it is exerted a mechanical pressure. In Figure 6(a), no force is applied to the piezo.

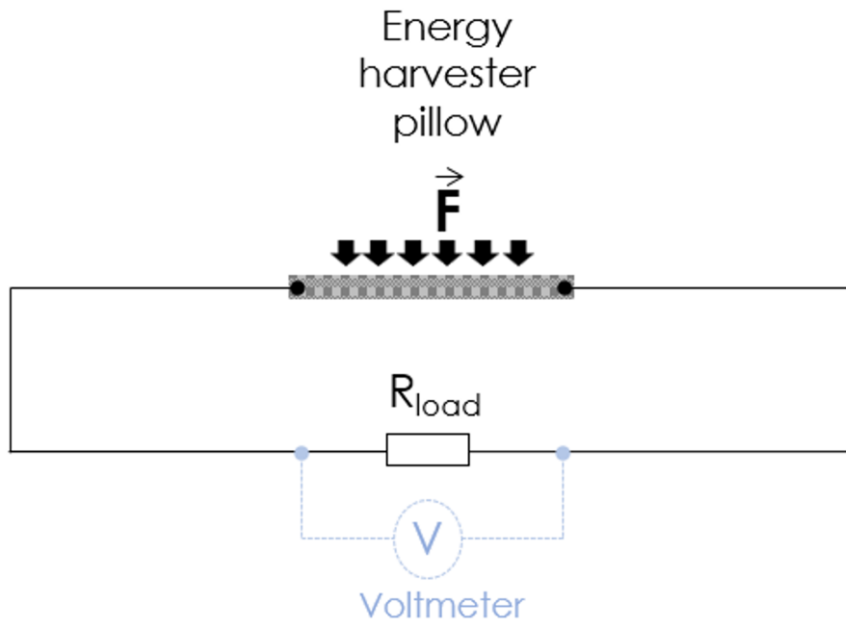


Figure 5: Electrical equivalent circuit of the pillow experimental test.

As illustrated by Figures 6(b) and 6(c), the test consists in pressing the pillow by the hand and noting the instantaneous variation of the electrical voltage. Figure 6(b) shows a voltage of approximately  $U = 12.5$  mV for a simple pressure of the index.

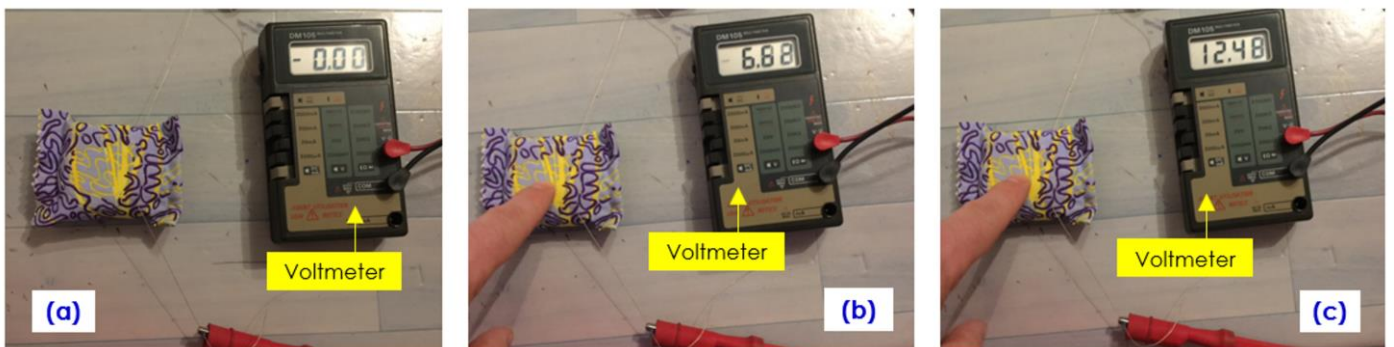


Figure 6: Photo of the harvester pillow tests: (a) rest, (b) and (c) under pressure of a finger.

For the voltmeter input impedance  $R = 1 \text{ M}\Omega$ , we have can estimate the average electrical power by the relation:

$$P_e = \frac{U^2}{R} \approx 156 \text{ pW} \quad (2)$$

Given this average power, a rapid analysis of the harvested average electrical energy is proposed in the following section.

## 4. Assessment of the generated electrical energy in function of the environment mechanical energy exploration

This energy field analysis is applied to an ideal case where the pressure is uniform over the entire surface and exerted in the same way during the duration of the experiment.

### 4.1 Theoretical approach of the energy exploration

Under the same condition as in Figure 6(b), we can consider an empirical analysis of the average energy harvested with a surface chair:

$$S > 4S_p = 4\pi r^2 \quad (3)$$

In this case, it will then be possible to assemble several or identical piezoelectric np placed in a layer so that their outputs of electrical energy are added:

$$E_{e_{ave}}(n_p) = \sum_{k=0}^{k=n_p} E_k = n_p E_e \quad (4)$$

For example, by having an armchair incorporating the principle CAMEH of Figure 1 having a square surface  $S$ , it is considered possible to place a maximum number of piezos:

$$n_p = \left[ Ent \left( \frac{\sqrt{S}}{2r} \right) \right]^2 \quad (5)$$

where  $Ent(x)$  expresses the upper integer part of the real number  $x$ . Therefore, the corresponding average energy level is:

$$E_{e_{ave}}(S) \cong \frac{U^2}{R} \left[ Ent \left( \frac{\sqrt{S}}{2r} \right) \right]^2 \quad (6)$$

## 4.2 Approximated empirical assessment of average harvested energy from $S=1 \text{ m}^2$ equivalent surface

For this digital application, it is considered that 625 identical samples of the piezo tested in paragraph 3.2 are placed on a square surface  $S = 1 \text{ m}^2$ . Then, the average energy generated from expression (6) is calculated. Figures 3(a) and 3(b) respectively represent the plots of the level of this electrical energy on a linear scale and log-log for a pillow exerting a pressure lasting up to 1 h.

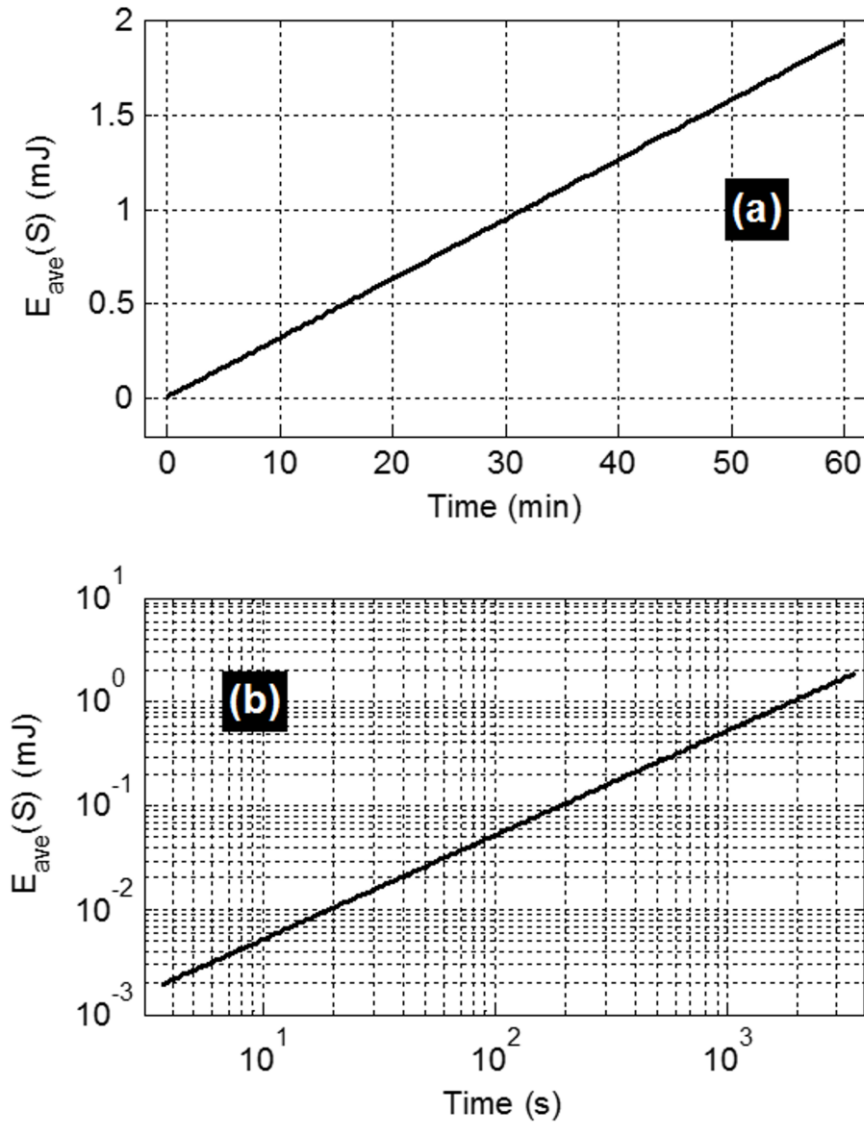


Figure 7: Estimation of the electrical energy of the piezo in the test condition of Figure 6(b).

This figure explains that for 1 h, this test condition allows the piezo to harvest average electrical energy up to about  $E_{ave} = 2$  mJ. But in the future, this energy level can be easily improved with a piezo with better performance under a better test protocol.

## 4. Conclusion

A feasibility study of a harvester pillow of mechanical micro-energy and converting it into electrical energy is presented. This pillow incorporates a piezoelectric sensor for mechanical energy and manufactured from materials manufactured by the company FILIX® [14]. A prototype was manufactured as proof of concept. Experimental test results have confirmed the feasibility of converting energy by pressure.

## **Acknowledgements**

Acknowledgement is made to the France Normandy Region for the “FIL HARMONIQUE” project grant no. 18E00151 2017-2019 support of this research work, research and publication of the present article.

The authors declare that there is no conflict of interest regarding the publication of this paper.

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