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Piezoelectricity as a Renewable Energy Source: A Literature Review

Robson Pereira Martins, and Geraldo Lúcio Tiago Filho
Federal University of Itajubá (UNIFEI), Brazil

Abstract: The electric energy resulting from the pressure exerted on materials known as piezoelectric, is called piezo-electricity. Since its discovery in 1880, piezoelectricity has been the subject of scientific, industrial and energy studies. Its application ranges from implants and medical devices to shoes that light up LEDs and tracks in busy locations for power generation. In Brazil, its use is recent and, for the time being, it does not represent a large scale renewable energy source, despite being considered a source of clean energy, low impact to the environment and biocompatible (adaptable to the human body). Through a bibliographical research, the contributions of the several studies developed on piezoelectricity, focusing on its application in the area of renewable energies will be presented. At the end of this article, we will present the considerations regarding the trajectory of the piezoelectricity to the present day, observations regarding the use of piezoelectricity as a source of renewable energy and suggestions for future work.

Key words: piezoelectricity, renewable energy, bibliographic research

1. Introduction

Several countries have turned to sustainable renewable energy sources because of concerns about the environmental consequences of the greenhouse effect and the burning of fossil fuels, as well as the risk of environmental accidents from nuclear energy [1].

In addition to environmental and climate preservation, increased demand for energy from population growth and technological/industrial development has also led to a growing demand for alternative renewable energy sources [2].

According to Bermann [3], the current challenge of Brazil is to meet the growing demand of its population for energy, with environmental responsibility, efficiency and equality.

This paper intends to show the trajectory of the piezoelectricity studies, from the discovery of piezoelectric materials, to their current use as a renewable, sustainable energy source, in small, medium and large scales, in several fields of application.

2. Theoretical Reference

Piezoelectric minerals (such as tourmaline and quartz) under directed pressure generate a positive electric charge on one side and a negative electric charge on the other side [4].

Klein and Dutrow [4] affirm that the property of piezoelectricity was first detected in quartz in 1881 by Pierre and Jacques Curie, but approximately 40 years passed before it was used in a practical way. During the end of World War I, it was discovered that sound waves produced by a submarine could be detected by the piezoelectric current generated when they collided with a submerged quartz plate.

After the publication of the Curie brothers' study, the term *piezo-electricity* was coined by Hankel (1881), and means "*pressure electricity*" [5].

The discovery of the direct piezoelectric effect by the Curie brothers also allowed Gabriel Lippmann to

Corresponding author: Robson Pereira Martins, Master Program Student; research areas/interests: renewable energies, environment. E-mail: rob81_martins@yahoo.com.br.

show a year later the reverse piezoelectric effect, which is the ability of piezoelectric materials to suffer mechanical deformation when applied to opposite ends of the electric field [6].

Already in the twentieth century, during the First World War (1914-1918), the need to detect undersea sounds arose, which led Paul Langevin in 1917 to develop a device of quartz crystals surrounded by metal plates, to generate pulses of ultrasound and receive echoes. The invention, showed in Figure 1, became known as a Langevin transducer, and was patented in 1921 [7].

Considering its technological application, a piezoelectric transducer is an electromotive force sensor, as it responds to an external stimulus generating induced voltage [8].

A transducer is a measurement and control device in which the electric or magnetic field will be used for electromechanical energy conversion and whose physical characteristics will depend on its application. Microphones, phonograph capsules, sensors, and speakers are examples of transducers [9].

Low-cost piezoelectric transducers designed for power microgeneration are called *buzzers* [10].

Due to the use of quartz crystal transducers relying on high voltage generators, synthetic piezoelectric materials began to be developed in the 40s and 50s of the twentieth century: Barium Titanate piezoelectric ceramics by Japan and former USSR (Union of Soviet Socialists Republics); and lead zirconate piezoelectric ceramics by the US [11].

Piezoceramics can also compose piezoelectric generators. A piezoelectric generator set (Fig. 2) is composed by a piezoelectric generator (example: ceramic PZT), a charge controller (which harmonizes the voltage generated with the type of voltage required by the battery) and a battery [12].

Fig. 3 shows the electrical voltage 'E' that is generated by the compression and expansion of a piezoceramic part (piezoelectric generator) [12].

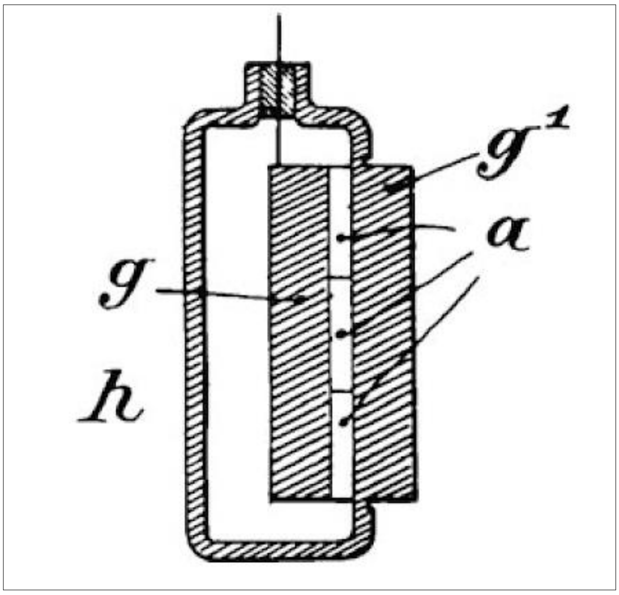

Fig. 1 Invention patented by P. Langevin in 1921. Ultrasonic steel plate device (g; g1) and quartz crystals (a).

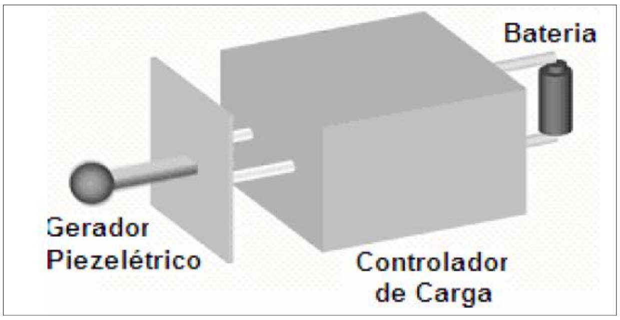

Fig. 2 Piezoelectric generator set.

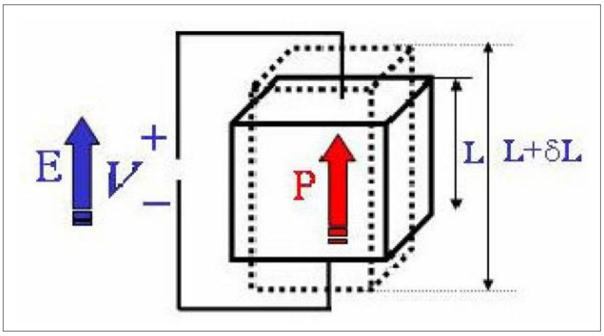

Fig. 3 Electric Power Generation as a function of "P" pressure.

Fig. 4 shows the two main modes of energy utilization (or piezoelectric effects): longitudinal and transverse [12].

Sensors and actuators, being able to configure light, compact and varied shaped devices, have been made of piezoelectric materials, especially piezoceramics.

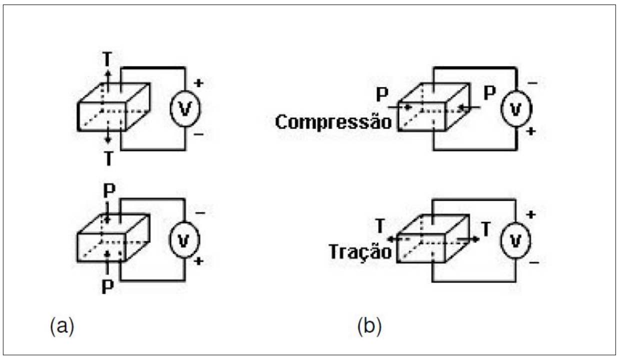

Fig. 4 Main piezoelectric effects. Longitudinal (a) and transverse (b) effect.

Already the thin ceramic tiles, due to their low cost, have been widely used by industries [13].

Constitutive equations allow the development of modeling and simulation of piezoelectric structures from the elastic, electrical and piezoelectric properties of the materials involved [13].

Still using constitutive and thermodynamic equations, it is possible to calculate the internal energy accumulated by a piezoelectric material, by the following Equation 1, in which dU represents an infinitesimal variation in internal energy, due to the work dW and the heat exchange dQ, both defined by interaction of the material with the external environment [13].

$$dU = dW + dQ \quad (1)$$

The two main fronts of studies involving piezo-electricity are: a) industry, through research involving the creation of synthetic and/or piezoelectric materials; b) simulation of its operationalities through mathematical models [13].

In small power generation, targeting small everyday demands, gadgets are diverse portable devices, connected by USB cable, such as smartphones, MP3 or MP4 players [10].

For medium and large-scale power generation such as shops, malls, homes, colleges, parking lots, streets, highways, the piezo-electric buzzer boards must be installed on the floor for use at the time of piezoelectric power generation, or for storage in rechargeable batteries [10].

In Brazil piezoelectric power generation is little used and known, but in Europe its use is little more already widespread, such as in the lighting of roads, football stadiums and nightclubs [10].

3. Discussion and Conclusion

For the development of this article a bibliographical review about piezoelectricity was performed, since its discovery, until its current use as energy source.

In the bibliographic review, the theoretical frameworks and set of theoretical references that support the fundamental focus of the theme should be presented [14].

We saw that the first studies of piezoelectric property came from the Curie brothers in 1881 and that Lippmann then discovered the reverse piezoelectric effect. Langevin, in the period of First World War, invented the quartz crystal transducer, which allowed the identification of submarine sounds.

We move on to the emergence of synthetic piezoelectric materials (such as piezoceramics) and continue with the contribution of piezoelectricity to electrical generators, sensors, as well as their use in small, medium and large power generation.

We also discussed how constitutional equations and thermodynamics can contribute to the calculation of the internal energy of a piezoelectric material and that the main lines of research in the area are aimed at the development of piezoelectric materials for industrial purposes or the simulation of functional properties by mathematical models.

We conclude that, since its discovery, piezoelectricity has been evolving in a structural way, reaching a range of use and knowledge for new applications.

As an object of study, we can say that piezoelectricity is a promising field that goes beyond power generation, as there will be great demand in various areas such as medicine, electronics, construction and shipbuilding, aviation, aerospace.

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