Prototype for Sustainable Power Generation from Motokinetics Losses in Urban Infrastructure through Piezoelectricity

Vitor Chaves de Oliveira, Sérgio Bimbi Junior, Lia Toledo Moreira Mota and Vagner Vasconcellos

Abstract — **In recent years, the demand for sustainable solutions in electric energy production has grown significantly. The reasons for this increase, begin on the evidence of a possible breakdown of the production model based on fossil fuels, undergo air quality improvement in urban environments and extend to economic concerns. Simultaneously, nowadays, it is observed that people's way of life has been consolidated in the context of towns. Consequently, to develop technologies aimed at implementing solutions for urban infrastructure systems becomes relevant. Added to this, lies the fact that electricity is categorized as essential to the modern life. And, to respond to this set of needs, means of power generation that are sustainable have to be sought. In this sense, this work developed a prototype that employs a technology that can be applied to this scenario, which presents recovery of lost energy to the environment, i. e., kinetic energy. And, for the proposed areas, such loss is dramatically demonstrated by engine mechanization, i. e., motokinetics. The selected technology that is capable of producing electrical energy from the losses of this process was Piezoelectricity. So, to consolidate the required combination, the prototype was built using embedded electronics supported by PIC, Programmable Interface Controller. Such microcontroller was selected because it offers key functionalities and advantages. In this work, it was programmed in low-level language, showing efficacy for conceiving the desired prototyping. As a result, this work delivered a small scale prototype with an exemplification of its use with a railroad model.**

***Index Terms* — Embedded electronics, Sustainable Generation, Urban Infrastructure, Motokinetics, Piezoelectricity.**

I. INTRODUCTION

Considering the world context of electric energy, there's been a continuous demand growth of in the last decades, with about 13% of this energy being generated from renewable sources and the rest produced primarily from fossil fuels [1]. Thus, it is worth noting that the exhaustion of these sources is expected by the end of this century and is associated with a possible increase in electricity costs over time in case this model of generation is perpetuated [2] [3]. It should also be considered that the cost of electricity over the last 60 years indicates a substantial increase trend in its price [4] [5]. Moreover, the tendency of demand increment for electricity is related, in a relevant but not exclusive way, to another factor that causes residential consumption to increase, which is the migration of people from the rural to the urban environment [6]. It is noteworthy that this consolidation of urbanization, that is, the allocation of people in cities is a worldwide trend with more than 54% of the population living in these environments [7] [8] [9].

In Brazil, these price and urbanization factors are even more expressive and lacking in proposals and solutions. This is because the country has one of the highest costs of electric power generation, as can be explained by a comparison in which a graph shows that Brazil occupies the second highest electricity cost in the world [5]. As for the urbanization issue, the last census, from the Brazilian Institute of Geography and Statistics, points that the nation is in the last stages of this process, with 84% of the population living in cities [10].

Considering the aforementioned tendencies and needs, activities and studies related to reuse, efficiency around the theme of sustainability became focus of attention [11] [12]. Keeping in mind these challenges, this paper aims to develop a prototype hardware and software to generate energy in a sustainable way through piezoelectricity. The reasons for choosing the technologies employed are explained as follows.

Pondering the magnified necessity for sustainable solutions and the growth of urbanized environments. And, with this enlargement of the fleet vehicles particularly in metropolitan regions in the country [13], it has been realized that a possible gain can be obtained capturing motorized energy dispersed to the environment by the concentrated traffic, that is to say, by the movement of these automobiles. And, when observed in the literature, it is observed that the design of solutions that work with this objective in these systems of urban infrastructure are scarce. In addition, it is emphasized the low and/or even inexistent offer of commercial solutions of electric power generation in a sustainable manner utilizing piezoelectricity in large scale. Thus becoming evident, the need to deepen studies and develop proposals around this theme. That is, to develop means of capturing this energy that is lost to the environment naturally, reusing it, thus generating energy called clean and sustainable.

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II. EMBEDDED ELECTRONICS

Embedded Electronics comprises hardware devices that can be programmed via software and coupled to a platform, such as a car, an industrial machine, a mobile device, etc. And, they are usually built to meet a particular need. For this, microcontrollers are generally used, which currently have integrated circuits, microprocessors and are limited to a given instruction processing capacity. Currently there are several types of microcontrollers, among which the PIC (Programmable Interface Controller), Arduino, Atmel with ARM cores (Acorn RISC Machine or Advanced RISC Machine) and hybrid systems addressing programmable logic and FPGAs (Field Programmable Gate Array). [14] [15] [16] [17].

For the purposes of this work, it was verified that, for cost-benefit reasons could be used the Arduino or the PIC, since both have a low cost for the proposed prototype. And, for technical reasons PIC was chosen. This is because PIC has a superior performance because its compiler provides the programmer with algorithms with advanced data control, not requiring the use of proprietary libraries which makes the performance optimization of clock cycles through the processing stack with inferior optimization of the data flow control. [14] [15] [16].

The Programmable Interface Controller or PIC has several types of integrated circuits available in the market, for this work the PIC16F877 was chosen. This is because the PIC microcontrollers of the 16xx family are on the market with several available peripheral architectures such as memory capacity and pin numbers of inputs and outputs on an 8-bit platform [14] [15] [16]. This processor has been chosen because its cost and processing capacity is compatible with the project, as well as the possibilities of system expansion or minimization using the same codes since their hardware registers are present in the same family and do not need to be modified if maintained the platform.

Considering the PIC16F877, it is observed that it is a microcontroller with a core of the order of 14 bits and of the 8 bits family. This PIC is manufactured by the company called Microchip Technology. The part of the name that contains the number 16 designates that it integrates the "MID-RANGE" family, being an 8-bit microcontroller. That is, implies that the ALU, or Arithmetic and Logic Unit, operates a limit of up to 8 bits for each set of 'words' at a time. While the F in this name informs about the memory that composes it is "Flash", a type of memory that allows fast access, typified in the category of EEPROM (Electrically-Erasable Programmable Read-Only Memory) that allows multiple records to be modified (written and/or deleted) at a time, i. e., in the same operation. In this schematic, it is also worth noting that every 14 bits (counting commands and addresses, being 8 bits of data) represent a line of this memory, that is, it forms 'words' of this size. In addition, the complete and precise identification of the PIC in question is provided by the three remaining characters of this name, identified by 877. This specific model has a processing of the order of 20Mhz, however the reference may be accompanied by a suffix -XX, indicating the maximum operating frequency of the clock present in the PIC. [18]

III. Piezoelectricity

Piezoelectricity is an electric charge that accumulates in certain materials when they are subjected to a variation of mechanical pressure, i.e., mechanical stress. This effect is observed in several types of materials such as proteins, DNA, bones, ceramics and crystals. It is interesting to note that the very word, piezoelectricity, derives both Greek 'piezein' which means pressure, and also the Greek 'electron' which is termed the amber material, one of the earliest in which electricity was observed. The history of piezoelectricity demonstrates that this effect was discovered by the French brothers Pierre and Jacques Curie in 1880. This was possible through crystals and the inverse piezoelectric effect ended up being deduced in mathematical form by thermodynamic principles by Gabriel Lippmann the following year. And after this, the Curie brothers experimentally confirmed this reversibility in the mechanical changes in crystals characterized from this as piezoelectric. In the course of these times, several studies continued in order to categorize whether or not a material has this property of generating voltage or potential difference that results in the production of electric charge, that is, of electric energy, when a mechanical stress is applied. And in 1910, a German book appeared, the 'Textbook in Crystal Physics'. This established two dozen categorizations of natural crystals segmented by tensile mechanical stress analyzes, obtaining piezoelectric constants for each of these classes. [19] [20].

The piezoelectric effect, as previously mentioned, is more noticeable in certain crystalline materials, such as ceramics and polymers. And, it is practically understood as an electromechanical interaction, that is, a linear relationship between the Coulomb forces of the electric state, linked to the voltage, and the mechanical force, linked to the physical stress of the material by pressure variation. This effect is a reversible process in materials that demonstrate the so-called direct piezoelectric effect, that is, both the electric field application presses the material and the pressure on the material causes the resulting electric field to be created. Thus, these materials change their dimensions when an electric field is applied on them and when they are stressed by mechanical forces the change of their dimensions generates electric charges of linear order. It is emphasized that after removing the electric field and/or without mechanical stress, these materials return to their state with the same original symmetry, without deformations. Figure 1 below demonstrates the effect mentioned in the quartz, which composes the piezoelectric sensor used in this work. While Figure 2 shows examples of piezoelectric sensors with quartz crystal core and metal-coated (bronze, aluminum or copper) as the one employed in this work. [20] [21] [22]

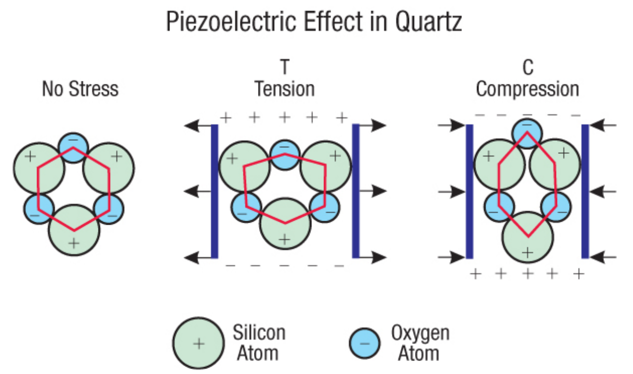

Fig. 1. Piezoelectric effect in Quartz.
Source: Reproduced and Adapted from Piezoelectricity - Piezoelectric Effect in Quartz... [21].

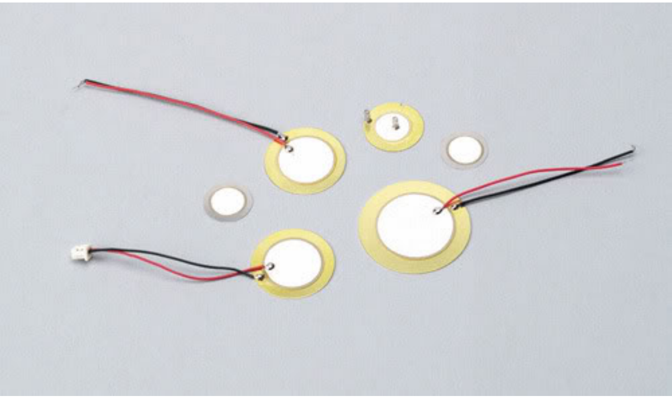

Fig. 2. Piezoelectric sensors with quartz crystal core and covered with metal (bronze, aluminum or copper).
Source: Reproduced and Adapted from Piezoelectric Sensors... [22]

Piezoelectricity is currently used in many applications in industry and in the context of cities. As an example, we can cite its extensive use in manufacturing processes for sensing: acting as load cell, machine vibration meter, transducer to drive devices, etc. In addition, it is worth mentioning its use in the generation of energy within the urban infrastructure built into the sidewalk and highway floors of some cities. As an example, it is relevant to mention the following. In Brazil and in the world there is a commercial solution used to supply energy to the batteries of emergency telephones installed in roads as a carpet embedded in the ground. Also worldwide, some speed cameras use piezoelectricity as sensors. In the Netherlands, this technology is also installed in stretches of asphalt and provides power to the batteries responsible for LED lighting in the road itself. New York has piezoelectric sensors installed on parts of the Times Square sidewalk to generate lighting power. In a subway station in the city of Paris, piezoelectricity is embedded in the stairs where many people circulate in order to illuminate parts of the station itself. As for studies of energy efficiency and generation capacity of this technology are still few, but some cite that the capacity of generation of a piezoelectric sensor, as mentioned above and used in this experiment, with the step of a person is in the order of 0.0000164 kWh by each step. [23] [24].

IV. METHODOLOGY

In order to achieve the goal of building the desired prototype, it was necessary to address the following combination and configuration of hardware and software.

Given a hardware architecture of a microprocessor, in general terms, for the system to be intact, it must have basic elements in order for the processor to be in operation. For the proposed system is applied, a voltage of + 5VDC, as a direct current power source, a quartz crystal with a 8Mhz frequency and a reset system connection to + 5VDC . Connected to the piezoelectric sensor is a mesh with an operational amplifier in order to increase the DC levels of the response of this sensor.

For the software, the PIC16F877 was programmed with the MikroC tool [25]. And this platform is used for C programming for PIC, in which the initial tests were designed before the hardware was made with the Proteus simulator [26] [27] [28]. Thus, to perform the reading of the analog input of the PIC16F877, from 0 to 5VDC with 10 bits of resolution, the analog inputs contained in the PORTA bus are used. And to have a proper reading is used a hardware interruption based on 8-bit TIMER0 with a time of 1ms. The interruption respects Equation 1 described as follows.

$$FClk_{interruption}=\frac{FClk_{Processor}}{4*Pre_{Scale}(256-TMR0)} \quad (1)$$

With these parameters, it is necessary to configure the registers to present the desired behavior. Then, we have by Equation listed as 2 the calculation for the interruption of 1ms.

$$1000=\frac{8000000}{4*64(256-TMR0)} \quad (2)$$

Therefore,
TMR0 = 224.75 for interruption of 1ms, rounded up to 225.

Next, it must be considered the analogue output that is necessary to be implemented for the project. The PIC16F877 has analog input modules capable of reading a 0-5VDC voltage at a 10bits resolution. For this process to occur it is necessary to configure the ADCON0 and ADCON1 registers for this function.

As for the software, it was developed in C language, encoding an algorithm that always works linked to the events of the interruption. That is, when a TMR0 is set, the T0IF_bit bit goes to logic level 1, when this occurs the system interrupts the data stack and answers the interruption with priority. At this time, a digital analog conversion is requested, when the GO/DONE bit of the ADCON0 register goes to zero it is ready for the conversion to be read. And, on this occasion, the values in ADRESH and ADREL, which are the analog input registers, are received in order to obtain a value allocated in an INT variable with a 16-bit size. This is done by scrolling instructions to correct the values. With this process contemplated in a comparative chain of 'ifs', the bar graph is activated in order to display the amplitude of the signal generated by the sensor.

From the code previously described, a simulation was conceived through the Proteus software. This platform has complete simulation of several hardware components, including the PIC16F877. In this way, all the schematic for the board that was implemented was constructed and tested previously, recording the described code in the PIC and making all the necessary connections. That is, simulating the complete operation of the physical design. In Figure 3 we have all these components in the simulator. The upper TRIMPOT_VARIAÇÃO (Trimpot Variation) functions as a potentiometer to adjust the gain of the amplifier to the parameters (ranges) described in the code, since the piezo signal may be too low for the microcontroller port to read. The second, TRIMPOT_VARIAÇÃO (Trimpot Variation) lower, makes, for purposes of simulation the role of emulating the piezo electric sensor response. While the RESET has the function of returning the system to the initial settings, an activation in case there is a problem with the circuit. The MICROCONTROLADOR (microcontroller) is the PIC16F877 with the code inserted and engraved, being the heart of this system. It is connected to the BARGRAPH so as to show from the bottom up the intensity of pressure with which the response of the piezo is perceived.

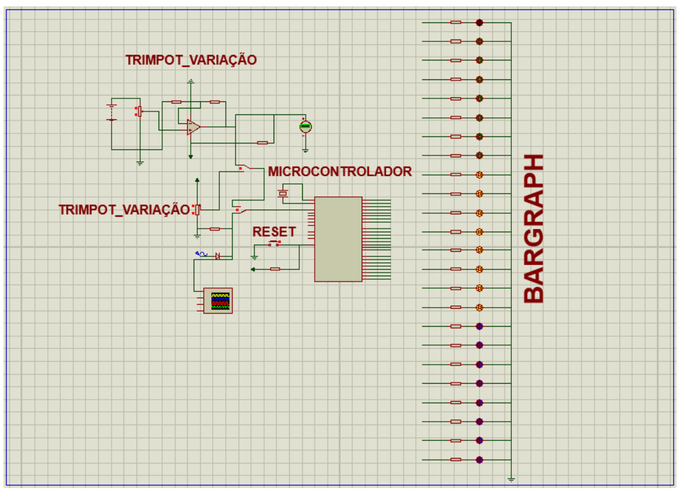

Fig. 3. Simulation Schematic via Proteus Software.

V. Results

The construction of the physical components resulted in the prototype demonstrated in this chapter. Figure 4 shows a component for recording and debugging PICs, through which is recorded the code developed and simulated in the computer for the PIC [29].

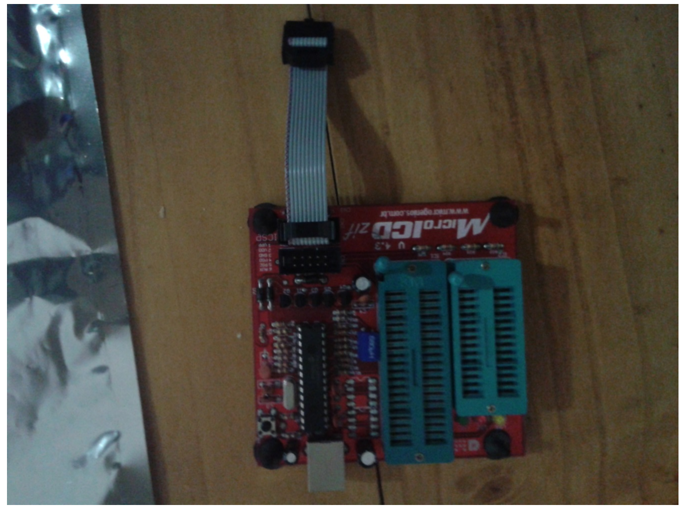

Fig. 4. MicroICD ZIF Recorder - PIC and PIC Recorder and Debugger via USB 2.0.

The phenolite plate with all components connected as predicted in the design and simulated is presented by Figures 5 and 6 below. It has the indication of each component: The PIC representing the embedded microprocessor; The Bargraph with a series of 23 LEDs that light up from minimum to maximum levels to demonstrate ranges of intensity of variation of the mechanical pressure suffered by the piezoelectric sensor, forming 24 levels from 0 to 23; The piezoelectric that captures the pressure variation through electric charge responsible for transforming mechanical force into an electric charge; The Source that feeds the circuit; the Amplifier that is associated with the Trimpot to categorize the read response levels of the sensor. In figure 6, it is shown the piezoelectric activation and the response shown by the Bargraph in this plate.

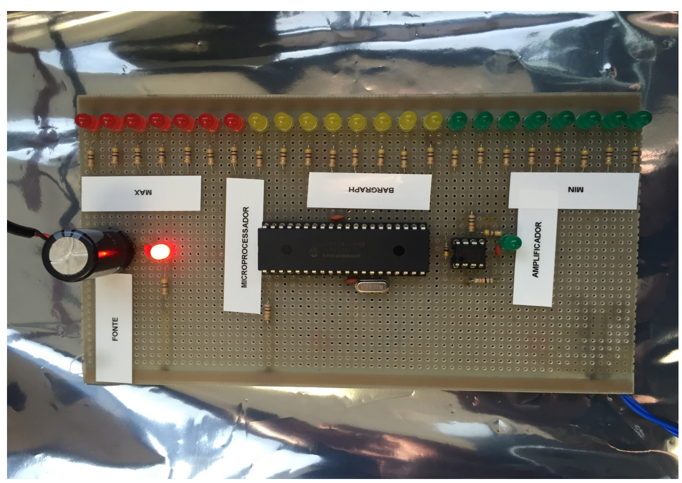

Fig. 5. Phenolite board with all components connected.

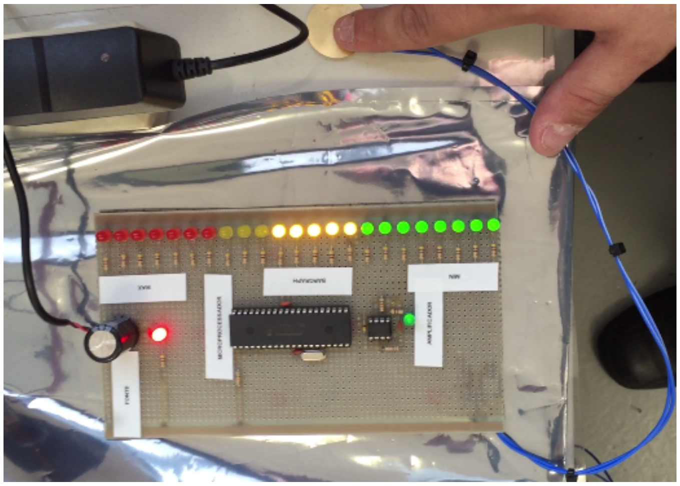

Fig. 6. Plate developed in operation with all components connected with the piezoelectric sensor activated.

In addition, with the objective of demonstrating the applicability of the prototype in urban infrastructure systems, the sensor and the plate were coupled to a model, observed in Figure 7. It is a model train, to simulate an application of the technology. That is, producing energy from engines motokinetics losses within the context of cities.

Fig. 7. Railroad Model conducting the automated demonstration of the experiment.

VI. Discussion

Given the search scenario for renewable energy sources, as well as the concentration of modern life in the context of cities. One of the main advantages of the application of piezoelectricity is to use motokinetic energy wasted by the means of transport and transform it into electrical energy. Obtaining in this way, a clean energy, once it is separated from natural resources as fossil fuels. In addition, it is noteworthy that this solution can be installed without major constructions such as a hydroelectric plant or huge areas for installation of equipment such as solar parks and wind farms. While it is observed that the main disadvantages of this technology are evidenced with respect to the variable generation, storage in batteries and distribution of the energy produced. This, because the generation varies according to the movement flow of transport, the cost to invest in batteries is always high and the distribution of energy needs frequency inverters, since the energy obtained is in direct current. Since in most cases where this technology is implemented, the energy generated is expended immediately, which limits its applicability.

In addition, it is worth pondering that this technology aimed at obtaining electric energy using piezoelectric material is in an embryonic stage when large scale is considered. This is because even though we do not find a wide range of information and studies about methods that use piezoelectric material to obtain energy, some experiments have already proven that it is possible to generate energy satisfactorily and charge batteries using these components. Through the analyzes carried out during the tests that were developed for this project, it was verified that there are numerous variables that influence the performance of the system. Added to this is the fact that each of these variables are extremely sensitive, advanced engineering is always required for the performance of such a circuit to be optimized. This may be one of the reasons why this type of application is not yet so widespread. Moreover, the fact that the variable and non-measurable system performance will make the payback time on the investment too long, increasing the risks.

VII. Conclusion

Finally, it is clarified that the piezoelectric material already has several applications, but a lot of investment in development, is still necessary so that its use as transducer of mechanical energy in electrical energy becomes viable at commercial levels. However, considering that the search for renewable energies is a trend, this material should be accentuated in the near future.

With this objective in mind and considering the context of the cities, it is seen that the development of this technology points to three aspects as future studies. The first is the necessary regulatory framework to be debated and created to interconnect these systems with this technology in the utility grid, since it generates in DC systems and with continuous generation variability, presenting a challenge that can harm the Electric Power System Power. The second is the very important involvement of traffic engineering companies to choose the best locations to embed this technology. It is necessary a multidisciplinary team to reconcile the studies of this area merging it with the knowledge of Electrotechnical and Electronics to make this solution feasible. The third point is manufacturing, with a great need for industry to focus on building larger scale solutions, from the simple construction of small transducers to robust and efficient generation devices that can rival other alternative energy sources.

The prototype conceived is finished and proved to be fully operational for the application selected, it aims to demonstrate it can applied in a number of facilities in urban infrastructure.

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Disclaimer

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and no ethical issues involved.

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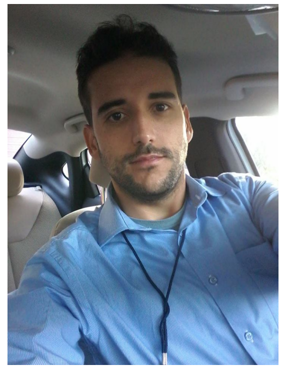

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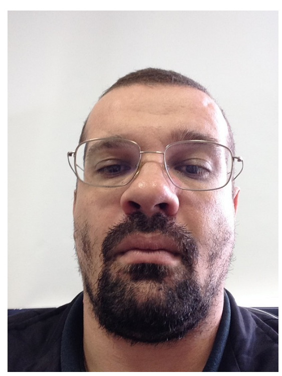

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