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PIEZOELECTRIC EFFECT-BASED ENERGY MICROGENERATION

MICROGERAÇÃO DE ENERGIA BASEADA EM EFEITO PIEZOELÉTRICO

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Abstract: This study presents the development of a piezoelectric mat prototype focused on microgeneration of energy from mechanical pressure, targeting sustainable applications in high-traffic areas such as educational institutions. The project is based on the property of certain materials, such as lead zirconate titanate (PZT), to generate electric charge when subjected to deformation. Thus, 40 piezoelectric buzzers arranged in a matrix were used, along with rectifiers and energy storage components. The main objective was to evaluate the technical and economic feasibility of the system, considering different electrical (series, parallel, and mixed) and structural configurations. The mechanical assembly was made with MDF boards, springs, and EVA layers to protect the sensors. Tests indicated that the Schottky diode (1N5817) was the most efficient due to its low forward voltage (0.24 V). With structural and connection adjustments, the best configuration achieved a current of 176.9 µA and a voltage close to 10 V, reaching a power output of approximately 30 mW. The data showed a proportional relationship between voltage and current (Ohm's Law), with a low standard deviation (3.25 mA), suggesting system stability at a small scale. The research confirms the system's potential to power low-consumption sensors, contributing to sustainable solutions for the educational

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sector. The abstract should describe the objectives, context, and significance of the research, methods, results, and main conclusions of the paper in about 300 words. It should not include formulas or references to a bibliography. It must be written in only one paragraph.

Keywords: energy generation; piezoelectricity; sustainability; piezoelectric buzzers; education.

1. INTRODUCTION

The growing demand for sustainable energy sources is driving the development of technologies capable of converting ambient energy into usable electricity. In this context, piezoelectricity—a phenomenon discovered by the Curie brothers in 1880—has been extensively studied as a viable solution for the microgeneration of electrical energy from mechanical pressure and vibrations. This technology stands out for enabling the direct conversion of kinetic energy, derived from everyday movements, into electricity without the need for external sources or fossil fuels. High-traffic environments such as schools, universities, and public spaces represent strategic opportunities for the implementation of piezoelectric systems, especially when integrated into floors, staircases, and circulation surfaces. The energy generated can be used to power low-consumption sensors, automation systems, LED lighting, or Internet of Things (IoT) devices, thus contributing to greater energy efficiency and reduced environmental impact.

Numerous national and international studies have explored the potential of this technology. Experimental prototypes have already demonstrated the capacity to generate power on the order of milliwatts per step, as shown by Selim et al. (2024) and Atik et al. (2023). These studies show that the application of piezoelectric systems in urban and institutional contexts is not only feasible but can also provide an accessible and educational alternative for promoting sustainability. In this context, IoT stands out in the design of low-power devices by enabling the development and use of efficient sensors that consume minimal energy while providing crucial data for managing and optimizing processes, whether in smart cities, agribusiness, healthcare, or smart homes. The integration of these devices with data analysis platforms and web connectivity not only offers convenience but also provides opportunities to enhance efficiency and sustainability across various sectors, making operations more economical and environmentally friendly.

This work proposes the development of a low-cost piezoelectric mat using commercial buzzers as transducers to capture the mechanical energy generated by walking in educational institutions. The objective was to assess the technical and energy feasibility of the system, exploring its application as a tool for environmental awareness and technological innovation within the school setting.

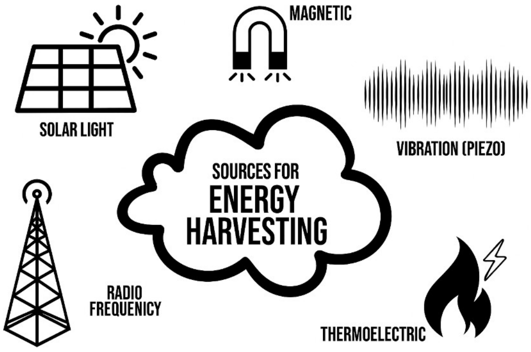


Figure 1. Sources for energy harvesting.

2. PIEZOELECTRICITY

Energy harvesting (also known as energy capture or waste energy recovery) is the process by which ambient energy from a system is converted into usable electrical energy. Energy harvesting allows electronic devices to operate in locations where no conventional power source is available, eliminating the need to install wiring or make frequent visits to replace batteries.

An energy harvesting system typically includes circuits to charge an energy storage cell and manage power, providing regulation and protection. In the Figure 1 illustrates the various forms of ambient energy harvesting, including light sources (captured by photovoltaic cells), vibration or pressure (captured by a piezoelectric element), thermal differentials (captured by a thermoelectric generator), radio frequency energy (captured by an antenna), and even biochemically produced energy (such as cells that extract energy from blood glucose). However, to optimize energy harvesting, it is necessary to develop extraction circuits and energy storage devices (Figure 2). The electronic circuits must minimize the losses of the extracted energy, typically employing AC/DC converters composed of nonlinear circuits with diodes, transistors, synchronized switches, among others. Therefore, for the effective use of harvested energy, a source, an extraction circuit, and a storage device are required, as illustrated in Figure 2.

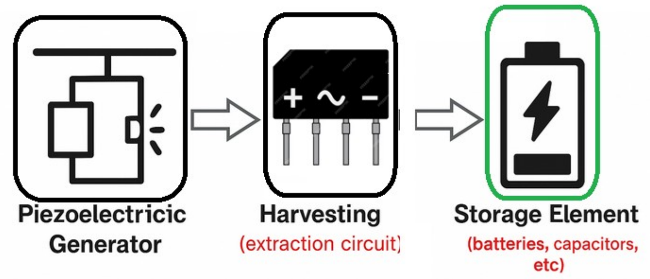


Figure 2. Energy Harvesting Flow.

In this work, the energy harvesting source will be based on piezoelectric materials, generating the so-called piezoelectricity. As previously mentioned, piezoelectric materials are characterized by their ability to deform in the presence of an electric field and also to generate an electric field when mechanically deformed. Thus, in piezoelectric materials, both the mechanical stress and the electric displacement depend on the combined values of electric field and mechanical strain. Equations 1 and 2 below represent the constitutive equations for an orthotropic piezoelectric material, presented in the “e” and “d” forms, respectively, using the standardized notation of the Institute of Electrical and Electronics Engineers (IEEE). (Carbonari, 2003; IEEE, 1996; IKEDA, 1996).

In equations (1)–(2), [c] is the 6×6 stiffness matrix of the material, [s] is the 6×6 compliance (elasticity) matrix, [e] is the 3×6 inverse piezoelectric coupling matrix, [d] is the 3×6 direct piezoelectric coupling matrix, and [ε] is the 3×3 dielectric permittivity matrix of the material. {T} is the 1×6 mechanical stress vector, {S} is the 1×6 strain vector, {D} is the 1×3 electric displacement vector, and {E} is the 1×3 electric field vector. The superscripts E, S, and T denote that the given property applies, respectively, under constant electric field, constant mechanical strain, and constant mechanical stress.

$$\begin{Bmatrix} \{T\} \\ \{D\} \end{Bmatrix} = \begin{bmatrix} [c^E] & -[e]^t \\ [e] & [\varepsilon^S] \end{bmatrix} \times \begin{Bmatrix} \{S\} \\ \{E\} \end{Bmatrix} \qquad (1)$$

$$\begin{Bmatrix} \{S\} \\ \{D\} \end{Bmatrix} = \begin{bmatrix} [s^E] & -[d]^t \\ [d] & [\varepsilon^T] \end{bmatrix} \times \begin{Bmatrix} \{T\} \\ \{E\} \end{Bmatrix} \qquad (2)$$

Thus, when the piezoelectric element is pressed, a positive voltage (+e) is generated. However, when the applied force ceases and the element returns to its original position, a negative voltage (−e) appears. This indicates that under vibration, the voltage at the terminals of the piezoelectric element alternates between positive and negative peaks. Therefore, it makes complete sense to include a rectifier bridge as a key component of the energy harvesting extraction circuit. A rectifier is essential in an energy harvesting circuit, as it converts the alternating current (AC) generated by ambient energy sources into direct current (DC), which can be stored or used to power low-power electronic devices. In energy harvesting systems, sources such as mechanical vibrations (piezoelectrics), electromagnetic radiation (RF), or even thermal variations often generate AC signals, which cannot be directly used by devices that require a stable DC supply, as illustrated in Figure 2.

A. BUZZER

The use of commercial piezoelectric buzzers as low-cost energy harvesting devices has been widely reported in the literature, highlighting their applicability in systems designed to generate energy from mechanical vibrations (Cardoso et al., 2006; Mishra et al., 2016). In this context, the piezoelectric ceramic employed in this study is a cost-effective component commonly referred to as a piezoelectric buzzer. It is composed of a passive brass diaphragm, a piezoelectric ceramic disc, and a layer of conductive epoxy adhesive, as illustrated in Figure 3.

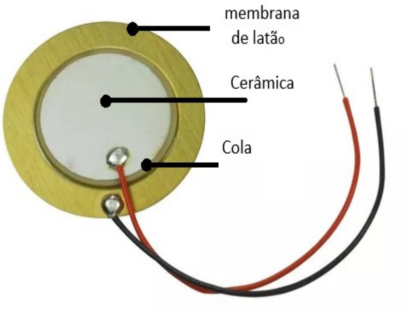


Figure 3. Piezoelectric Buzzer

The buzzer's passive diaphragm is an alloy composed of copper and zinc in proportions that vary by manufacturer, typically averaging around 50% of each element. This alloy is commonly known as brass. As a commercial component, the buzzer is produced by various manufacturers in sizes ranging from 10 cm to 50 cm, with variations in the thickness and stiffness of the brass diaphragm. In general, the piezoelectric buzzer is a device used to generate sound at various frequencies. However, due to its piezoelectric properties, it can function either as an actuator or a sensor. When an electric voltage is applied to its terminals, it operates as an actuator, producing sound and vibration. The piezo buzzer is widely used in applications such as alarms, timers, and audio indicators due to its low cost, energy efficiency, and ease of control. On the other hand, when mechanical force is applied to its structure, an electric voltage appears at its terminals, allowing it to function as a sensor and energy generator.

According to Vieira et al. (2016), the buzzer responds to mechanical compression and decompression by generating both positive and negative voltage peaks, which plots voltage amplitude over time. The generation is pulsed in nature, with the highest amplitude occurring during compression, producing a larger negative voltage peak. Another relevant observation is the pulse duration, which is less than one second. Nevertheless, the voltage generated can reach relatively high values, making this device highly promising for use as a sensor. Similar findings are reported by Garcia et al. (2012), who optimized piezoelectric buzzers for micropump applications, reinforcing their potential in low-power sensing and actuation systems.

B. ENERGY HARVESTING CIRCUIT

Piezoelectric buzzers inherently produce alternating voltage with both positive and negative cycles, when subjected to mechanical stress (Vieira et al, (2016). To convert this output into a usable DC supply, it is essential to include a rectifier circuit in the energy harvesting system. As noted in early studies, harvesting electrical energy from an AC source like a piezoelectric transducer into a DC storage device such as a battery or capacitor requires AC–DC conversion, for which diode-based or transistor-based rectifiers are commonly used (Ottman et al., 2002).

According to Pradeesh el al. (2022), a rectifier is a core component in piezoelectric energy harvesting circuits, playing a crucial role in interface design to ensure energy can be effectively captured, regulated, and delivered to the load. The authors emphasize that interface circuits must be carefully designed to maximize conversion efficiency and minimize energy loss.

Ottman et al. (2002) proposed an adaptive energy harvesting circuit (Figure 4) that efficiently converts the alternating voltage from a piezoelectric transducer into usable DC power. The system includes an AC–DC rectifier followed by a switch-mode DC–DC converter with an adaptive control algorithm that adjusts the duty cycle to maximize power transfer to the battery. Acting similarly to MPPT systems, this approach increased harvested power by over 400% compared to unregulated charging, proving effective under varying mechanical excitations and compatible with diverse piezoelectric configurations.

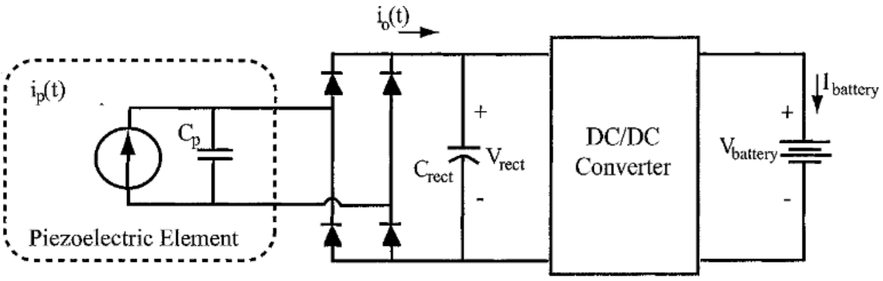


Figure 4. Piezoelectric Buzzer

In our work, we will not use a DC–DC converter; instead, the circuit will include only a rectifier composed of fast recovery Schottky diodes and a 100 µF@16 V capacitor for filtering. Regarding energy generation using piezoelectric buzzers, a set of units connected in series-parallel configurations is employed to increase the overall output voltage and current levels.

C. SYSTEM ARCHITECTURE

The structure of the proposed system is divided into three main parts: energy generation, rectification, and storage (Figure 5), representing the sequential stages of the energy conversion process.

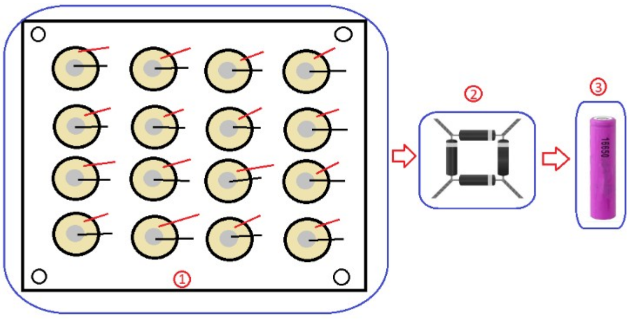


Figure 5. Structure of the proposed system

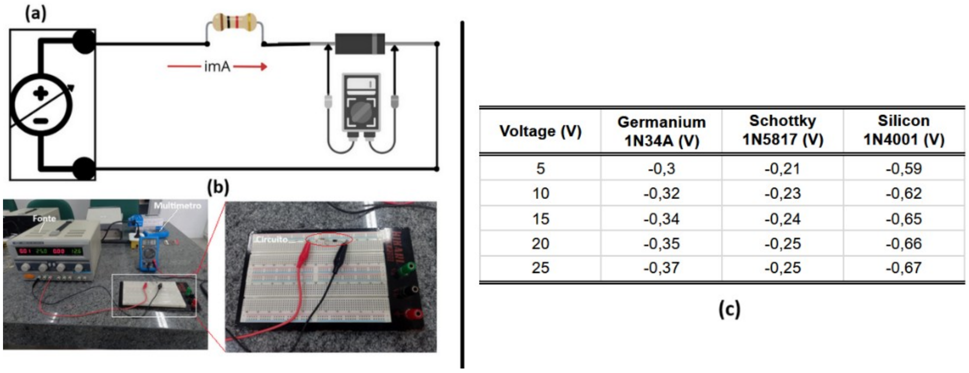
Stage 1- Generation: The matrix consists of several piezoelectric devices arranged in parallel or series configurations. Each piezoelectric element operates under cyclic deformations, such as vibrations or pressures applied to the disk. The type of piezoelectric device selected and its physical configuration directly influence the system's performance. Typically, piezoelectric buzzers generate voltage in the range of 1 V to 20 V, depending on the applied force. Moreover, the number of elements in the matrix affects the energy density of the system, enabling greater energy harvesting in smaller areas.

To assemble the prototype, 30 mm holes were drilled to mount the buzzers onto an MDF board measuring 27 cm × 16 cm. After gluing the buzzers in place, a second MDF board was positioned on top, forming a sandwich structure: the piezoelectric buzzers were enclosed between the first and second MDF layers. The boards were fastened together using six sets of screws, nuts, and washers, with springs inserted between the layers. This design allows compression movement of the piezoelectric elements without damaging them. The assembled structure can withstand loads of up to 100 kg without compromising the integrity of the ceramic disks, while still enabling the necessary mechanical displacement.

For the electrical connections, the red wire was soldered to the brass diaphragm, and the black wire to the piezoelectric ceramic layer. All 40 units were soldered using the same configuration and positioning. To ensure gentle mechanical contact between the top MDF layer and the ceramic element, a layer of EVA (ethylene vinyl acetate) was placed over each piezoelectric disk, helping to reduce mechanical impact and protect the ceramic surface.

3. RESULTS AND DISCUSSION

In order to analyze the main component for the development of a low-power extraction circuit, an experiment was conducted using a variable DC power supply (0–25 V) connected in series with a 100Ω resistor and a diode (Figure 6). In this experiment, three types of diodes were tested: a germanium diode, a Schottky diode (1N5817), and a standard rectifier diode (1N4001). The goal was to determine which diode exhibits the lowest forward conduction voltage.



Voltage (V)	Germanium 1N34A (V)	Schottky 1N5817 (V)	Silicon 1N4001 (V)
5	-0,3	-0,21	-0,59
10	-0,32	-0,23	-0,62
15	-0,34	-0,24	-0,65
20	-0,35	-0,25	-0,66
25	-0,37	-0,25	-0,67

Figure 6. (a) Illustration of the experimental electrical circuit; (b) Experimental setup; (c) Experimental Results

A total of five measurements were conducted for each diode type to determine the mean forward voltage drop and its associated standard deviation. The germanium diode exhibited an average forward voltage of 0.34 V with a standard deviation of 0.02 V. The Schottky diode (1N5817) demonstrated a mean value of 0.24 V and a standard deviation of 0.01 V. The silicon diode (1N4001) recorded an average forward voltage of 0.64 V with a standard deviation of 0.02 V. These results are consistent with the expected electrical behavior of each diode technology, particularly in relation to their characteristic threshold voltages during conduction.

Therefore, according to the project's requirements, the choice of diode for the piezoelectric mat depends on low forward voltage and fast reverse recovery time. Thus, the Schottky diode 1N5817 was considered the most balanced option, given its low average forward voltage (0.24 V) and fast reverse recovery time (50 ns). Accordingly, the rectifier bridge was assembled using four 1N5817 diodes.

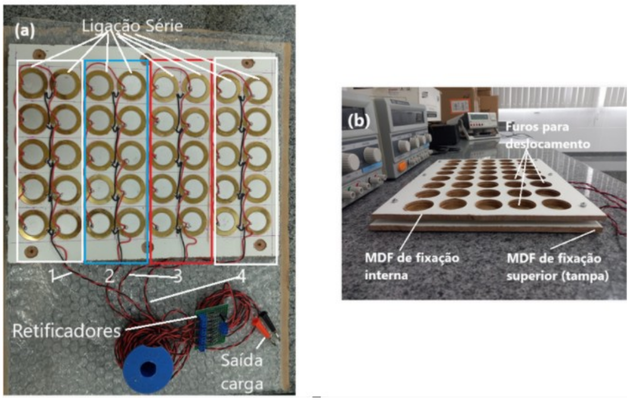


Figure 7. (a) Configuration of series and parallel connections; (b) Full experimental setup

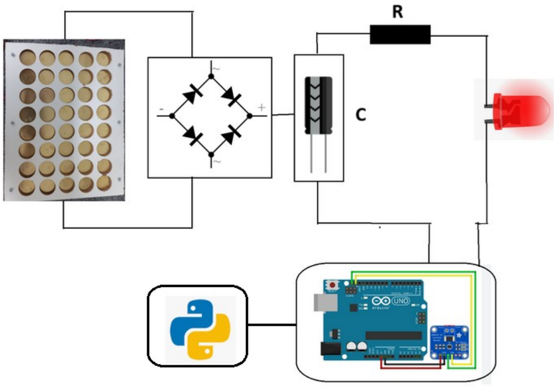
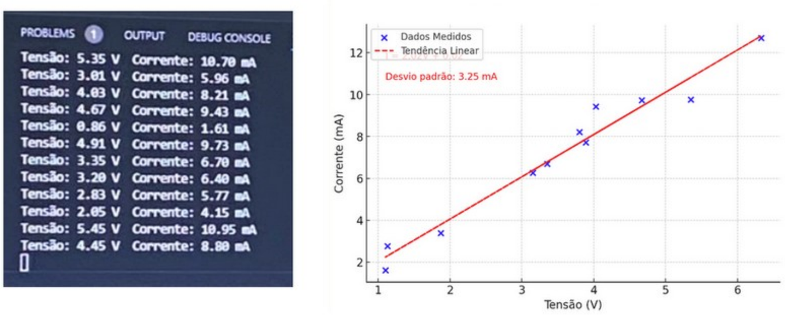


Figure 8. Current Measurement Circuit.

In the Figure 8 presents the circuit developed for measuring the electric current generated by a piezoelectric matrix composed of multiple elements arranged in parallel. When subjected to mechanical pressure, the matrix generates an alternating voltage that is rectified by a diode bridge, converting the output into direct current. This voltage is then smoothed by an electrolytic capacitor, allowing temporary energy storage. The load, formed by a resistor and an LED, enables the dissipation of the generated energy, allowing visualization of the system's operation. A current sensor (INA121), coupled to the circuit, monitors the intensity of the current flowing through the load. The captured data is sent to an Arduino Uno microcontroller, which performs analog reading and signal conversion. In parallel, the system is connected to a Python programming environment, which collects, stores, and analyzes the data received via serial communication. This experimental setup allows the evaluation of the piezoelectric matrix performance under different pressure conditions, providing input for the design and application in energy harvesting systems. The circuit is low-cost and shows potential for use in educational projects and prototypes focused on sustainability.



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Tensão: 5.35 V  Corrente: 10.70 mA
Tensão: 3.01 V  Corrente: 5.96 mA
Tensão: 4.03 V  Corrente: 8.21 mA
Tensão: 4.67 V  Corrente: 9.43 mA
Tensão: 0.86 V  Corrente: 1.61 mA
Tensão: 4.91 V  Corrente: 9.73 mA
Tensão: 3.35 V  Corrente: 6.70 mA
Tensão: 3.20 V  Corrente: 6.40 mA
Tensão: 2.83 V  Corrente: 5.77 mA
Tensão: 2.05 V  Corrente: 4.15 mA
Tensão: 5.45 V  Corrente: 10.95 mA
Tensão: 4.45 V  Corrente: 8.80 mA
▯
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Figure 9. Current Measurement Results.

The red line in the Figure 9 represents the linear fit of the data, describing the overall observed behavior. The standard deviation, indicated as 3.25 mA, quantifies the dispersion of the points relative to the trend line, being moderate and suggesting small variations, possibly attributed to system noise or external factors related to the setup. This type of behavior is typical of simple circuits, such as resistors or systems based on piezoelectric materials, in which the current responds linearly to the applied voltage. However, the deviations of the points from the trend line may result from experimental errors, such as inaccurate measurements, data acquisition issues, fluctuations in the applied voltage, or variations in circuit resistance.

Therefore, to enhance the understanding of the system's performance, a greater number of tests are required to more accurately quantify the piezoelectric generation per square meter as a function of the applied pressure and the frequency of the exerted force. Conducting these analyses will allow for the determination of the maximum pressure supported by the piezoelectric element, optimizing its efficiency and enabling more effective applications in energy harvesting and storage systems. Moreover, such studies will contribute to the development of strategies that minimize losses and expand the applicability of the technology in various personal, industrial, and environmental contexts. Nonetheless, for low-power consumption systems, the development and improvement of piezoelectric energy harvesting may represent a promising path in the future. Furthermore, the extractor circuits deserve significant attention, as they are capable of performing their functions while consuming less energy.

4. REFERENCES

Pradeesh, E. L. et al. A review on piezoelectric energy harvesting. Microsystem Technologies, v. 28, n. 8, p. 1797-1830, 2022.

Ottman GK, Hofmann HF, Bhatt AC, Lesieutre GA (2002) Adaptive piezoelectric energy harvesting circuit for wireless remote power supply. IEEE Trans Power Electron 17:669–676.

Carvalho, J.C.M., Martins, D., Simoni, R., and Simas, H., 2018. *Multibody Mechatronic Systems - Proceedings of the MUSME Conference held in Florianópolis, Brazil, October 24-28, 2017*. Mechanisms and Machine Science. Springer International Publishing.

Choma, E.F. and Ugaya, C.M.L., 2017. “Environmental impact assessment of increasing electric vehicles in the brazilian fleet”. *Journal of Cleaner Production*, Vol. 152, pp. 497–507.

EPE, 2022, *National Energy Balance 2022*, *Final Report* (in Portuguese), Empresa de Pesquisa Energética EPE, Rio de Janeiro, e.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicação-675/topico-638/BEN2022.pdf. Accessed 02 May 2025.

Fernandes, G.H.N., Bazon, V.T., Barbosa, L.M.Q., França, P.H.P., da Silva, M.B., Uddin, M., Martins, P.S. and Machado, Á.R., 2023. “Performance comparison between internally cooled tools and flood cooling during grey cast iron turning”. *Journal of Manufacturing Processes*, Vol. 85, pp. 817–831.

Mendes, N., Moura, L.M. and Riquelme, S., 2024. “Device for measuring atmospheric longwave radiation and its measurement method (in Portuguese)”. Patent, INPI - Instituto Nacional da Propriedade Industrial, Registry number: BR1020180737406, Application date: November 19, 2018, Grant date: September 10, 2024.

Mendonça, P.T.R. and Fancello, E.A., 2019. *The method of finite elements applied to mechanics of solids (in Portuguese)*. Editora Orsa Maggiore, Florianópolis.

Miyawaki, B., Mariano, A., Vargas, J., Balmant, W., Defrancheschi, A., Corrêa, D., Santos, B., Selesu, N., Ordonez, J. and Kava, V., 2021. “Microalgae derived biomass and bioenergy production enhancement through biogas purification and wastewater treatment”. *Renewable Energy*, Vol. 163, pp. 1153–1165.

MLA, 2020. *MLA works cited: Electronic sources (web publications)*. Modern Language Association, Purdue Online Writing Laboratory, Purdue University, https://owl.purdue.edu/owl/research_and_citation/mla_style/mla_ formatting_and_style_guide/mla_works_cited_electronic_ sources.html. Accessed 12 January 2021.

Nostrani, M.P., Kruss, P., De Negri, V.J. and Dell’Amico, A., 2019. “An aircraft actuator driven by digital hydraulic pumps”. In *Proceedings of the XVIII International Symposium on Dynamic Problems of Mechanics - DINAME 2019*. ABCM - Brazilian Society of Mechanical Sciences and Engineering, Armação de Búzios, RJ, Brazil.

Pitz, D.B., Marxen, O. and Chew, J.W., 2017a. “Direct numerical simulation of vacillation in convection induced by centrifugal buoyancy”. In *APS Division of Fluid Dynamics Meeting Abstracts*. pp. F33–006.

Pitz, D.B., Marxen, O. and Chew, J.W., 2017b. “Onset of convection induced by centrifugal buoyancy in a rotating cavity”. *Journal of Fluid Mechanics*, Vol. 826, pp. 484–502.

Porto-Hernandez, L., Vargas, J., Munoz, M., Galeano-Cabral, J., Ordonez, J., Balmant, W. and Mariano, A., 2023. “Fundamental optimization of steam rankine cycle power plants”. *Energy Conversion and Management*, Vol. 289, p. 117-148.

Santos, D.D., Furtado, G.M., Frey, S.L., Naccache, M.F. and de Souza Mendes, P.R., 2013. “Numerical investigation of elastic and viscous effects on inertial viscoplastic fluid flows”. In *Proceedings of the 22nd International Congress of Mechanical Engineering - COBEM 2013*. Ribeirão Preto, Brazil.

Santos, V.O., 2020. *Experimental and numerical analysis of the fretting corrosion mechanism at the stem-head and stem-cement contact surfaces of hip prostheses (in Portuguese).*

Master’s thesis, Graduate Program in Mechanical Engineering, Federal University of Santa Catarina, Florianópolis, Brasil.

Sestito, G.S., Venter, G.S., Ribeiro, K.S.B., Rodrigues, A.R. and da Silva, M.M., 2022. “In-process chatter detection in micro-milling using acoustic emission via machine learning classifiers”. *The International Journal of Advanced Manufacturing Technology*, Vol. 120, No. 11, pp. 7293–7303.

Souza, F.C.R., 2022. *Effect of Texturing on PCD Tools in the Turning of Aluminum 2011-T4 (in Portuguese)*. Ph.D. thesis, Federal University of Uberlândia, Uberlândia, Brasil.

Vargas, J.V.C., Ordonez, J.C., Gardolinski, J.E.F.C., Hovsapian, R. and Raimundo, R.C., 2021. “Real time hydrogen selfsupplied alkaline membrane fuel cell stack”. Patent, United States Patent and Trademark Office, Registry number: US20210194027A1, Application date: June 24, 2021.

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