COB-2023-XXXX
# ENERGY HARVESTING FOR TRUCK WEIGH-IN-MOTION SYSTEM
27th COBEM

**Rafael Domingues Baeta Neves**
**Michele Rodrigues Hempel Lima**
**Wellington Cassio Pinheiro**
**André Perin**
**Vinicius de Souza Grosso**
**Rafael Guariza**
Centro Universitário FEI – Av. Humberto de Alencar Castelo Branco, 3972-B - Assunção, São Bernardo do Campo - SP, 09850-901
rafaelneves1252@gmail.com

***Abstract.*** *This study aims to investigate and compare three types of energy harvesting technologies, including triboelectric, piezoelectric, and conventional electromagnetic generators coupled with a bump, for use as auxiliary power supplies in remote weighing sites. The evaluation was carried out under conditions like those observed on the site to provide accurate and realistic results. Results indicate that although the conventional electromagnetic generator coupled with a bump is three times more expensive than its piezoelectric and triboelectric counterparts, it generates approximately 145 more power per unit of area than the second-place technology. The results of this study provide valuable insights into the most appropriate technology for implementation as an auxiliary power supply on remote weighing sites, thus enhancing the competitiveness of ITWS manufacturers. In addition, the use of energy harvesting techniques to power weighing systems is an eco-friendly approach that can help in achieving the energy efficiency, sustainability, and decarbonization goals of the transportation industry.*

***Keywords:*** *UPS, energy storage, thermal analysis, heat dissipation.*

## 1. INTRODUCTION

Brazil is a large country with a strong presence in global agriculture and mining markets. Trucks transport a significant amount of goods through the road network. Monitoring load weight is vital for logistics control, administration, and safety. Intelligent Transportation Systems and weighing systems are gaining popularity in road digitization and modernization [1]. Fig. 1 presents the representation of the truck weighing system.

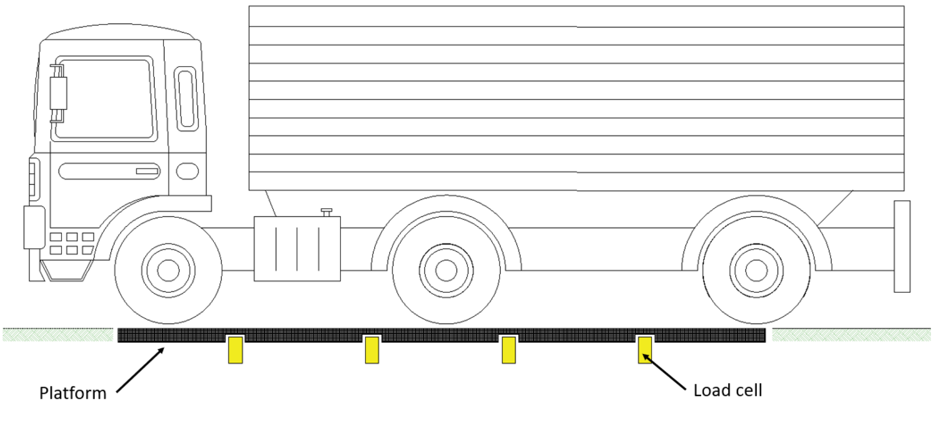


Figure 1. Representation of the truck weighing system.

The system for weighing road trucks can be constructed using either a concrete or steel platform that is embedded into the ground, specifically designed to withstand the weight exerted by the trucks during the weighing process. To facilitate the smooth entry and exit of trucks onto the scale, access ramps are employed [2]. The core component of the scale system comprises load cells, which serve as force transducers and play a pivotal role in accurate weight measurement [3]. Another indispensable element is the weight indicator, an electronic device that receives signals from the scale sensors and converts them into easily readable values. The weight indicator prominently displays the weight in a specified unit of measurement, such as kilograms or tons. Furthermore, some indicators offer additional functionalities, including data storage, report generation, or integration with data management systems. In order to ensure seamless vehicle entry and exit control, the system is further equipped with barriers and illuminated signals.

However, due to emerging technologies and a search for greater energy efficiency, sustainability, and power system decarbonizing are critical issues in the last few years and a huge demand for the world [4]. As a result, the use of energy harvesting sources has been an alternative to be added to the weighing system, making the scales more autonomous to optimize the use of energy sources, reducing costs, enabling measurement in remote locations, and collaborating with the environment [5-7].

Energy harvesting involves converting the available ambient energy in the environment into electrical energy. It operates on a much smaller scale compared to large-scale renewable energy generation, such as solar or wind power, which deals with megawatts of power. Energy harvesting focuses on micro- to milliwatts of power, making use of kinetic, thermal, solar, or electromagnetic radiation sources to generate electricity [8]. Fig. 2 presents the different energy harvesting technologies.

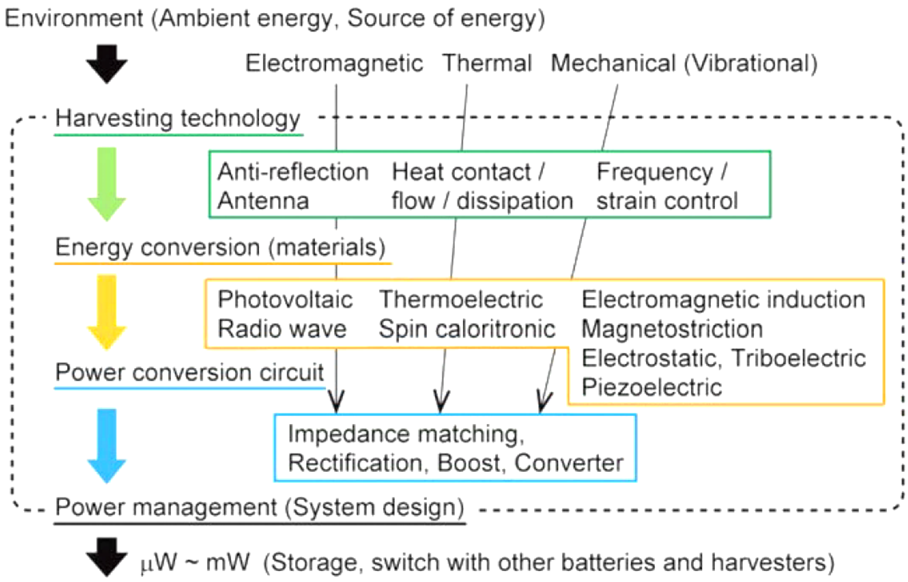


Figure 2. Energy harvesting technologies [9].

Triboelectric Nanogenerators (TENGs) are a fascinating and emerging technology in the field of energy harvesting. These devices are designed to convert mechanical energy, such as motion or vibrations, into electrical energy through a process called the triboelectric effect. TENGs have gained significant attention due to their potential to generate power from various environmental sources and their ability to provide a sustainable and renewable energy solution. The triboelectric effect is based on the principle of triboelectric charging, which involves the transfer of electrons between two different materials when they come into contact and then separate. When two dissimilar materials are rubbed together, one material tends to lose electrons and becomes positively charged, while the other material gains electrons and becomes negatively charged. This charge separation creates a potential difference, which can be harnessed as electricity. A typical TENG device consists of two layers of materials with different triboelectric properties, such as metals and polymers. These materials are structured in a way that allows them to come into contact and separate repeatedly, thereby inducing the triboelectric effect. When an external force, such as mechanical motion or vibrations, is applied to the TENG, the two layers rub against each other, leading to the generation of electric charges. The generated charges can be harvested and stored for various applications. TENGs offer several advantages over traditional energy harvesting technologies. Firstly, they are highly versatile and can generate electricity from a wide range of mechanical sources, including human motion, wind, water flow, and vibrations from machines or vehicles. This versatility makes TENGs suitable for a variety of applications, from self-powered wearable devices to powering remote sensors or even integrating them into infrastructure for energy harvesting. Another advantage of TENGs is their high-power density. Due to the triboelectric effect, TENGs can achieve relatively high-power outputs compared to other energy harvesting technologies. The ability to generate a substantial amount of electrical energy from small-scale devices makes TENGs attractive for portable electronics and low-power applications. Furthermore, TENGs have demonstrated excellent mechanical durability and long-term stability, allowing them to withstand repeated contact-separation cycles without significant performance degradation. This durability makes them suitable for applications where reliability and longevity are crucial. Researchers are actively exploring various design modifications and materials to enhance the performance and efficiency of TENGs. For instance, integrating TENGs with other energy harvesting technologies, such as solar cells or piezoelectric materials, can lead to hybrid systems that improve overall energy conversion efficiency. Triboelectric nanogenerators hold great promise for sustainable energy harvesting, enabling us to harness ambient mechanical energy and convert it into usable electrical power. With ongoing advancements and research, TENGs have the potential to play a significant role in powering our future, contributing to a more sustainable and energy-efficient world [10-11].

Piezoelectric materials are a unique class of materials that exhibit the piezoelectric effect, which refers to the ability to generate an electric charge in response to applied mechanical stress or deformation. Conversely, these materials can also undergo mechanical deformation when subjected to an electric field. This phenomenon allows piezoelectric materials to convert mechanical energy into electrical energy and vice versa. The piezoelectric effect is a result of the asymmetric arrangement of atoms or molecules within the crystal structure of the material. When an external force or stress is applied to a piezoelectric material, it causes a displacement of the charged particles, leading to the generation of a net electric polarization within the material. This induced polarization results in the appearance of an electric potential across the material, creating an electrical charge [12-17].

Electromagnetic generators are devices that convert mechanical energy into electrical energy through the principles of electromagnetic induction. They operate based on Faraday's law of electromagnetic induction, which states that a change in the magnetic field through a conductor induces an electromotive force (EMF) and subsequently generates an electric current. The basic construction of an electromagnetic generator typically consists of a rotating shaft or rotor, a set of magnets or electromagnets, and a stationary component known as the stator. The rotor is designed to rotate within the magnetic field produced by the magnets or electromagnets in the stator. As the rotor spins, the magnetic field lines passing through the conductive coils of wire in the stator change, thereby inducing an electric current in the coils [18].

Basing on this scenario, the objective of this research is to examine and contrast three different energy harvesting technologies: triboelectric, piezoelectric, and conventional electromagnetic generators combined with a bump mechanism. The goal is to evaluate their potential as supplementary power sources in remote weighing locations.

## 2. METODOLOGY

The three different energy harvesting technologies will be analyzed, having in base generated energy for a load cell that will operate with 12V and 30mA. As a result, it was considered a impedance of 300-ohm for the load cell in the tests conducted. The system involving triboelectric and piezoelectric generators will be a platform containing multiple of these generators. These generators will be strategically positioned across the platform to maximize energy harvesting from various sources. The platform's design will prioritize durability, reliability, and scalability to ensure long-term performance and adaptability to different environments. Electromagnetic generator system will be based on a specially designed speed bump positioned strategically in front of the scale. As the truck drives over the speed bump, its weight will cause the bump to lower temporarily. This downward motion will generate kinetic energy, which will be harnessed and converted into usable electrical power.

### 2.1 Triboelectric nanogenerators (TENG)

In the prototype using triboelectric nanogenerators, the following materials were used: Kapton tape, aluminum foil, and a sheet of regular notebook paper. These materials were subjected to friction by rubbing against each other, while a multimeter measured the voltage and current values obtained during the process (Fig. 4). The Kapton tape, known for its excellent insulating properties and flexibility, served as the base material for the nanogenerator setup. The aluminum foil, with its conductive properties, acted as one of the electrode materials, facilitating the transfer of charges during the frictional interaction. As the Kapton tape and aluminum foil were rubbed against the surface of the paper sheet from a common notebook, triboelectric charges were generated due to the difference in their electron affinity.

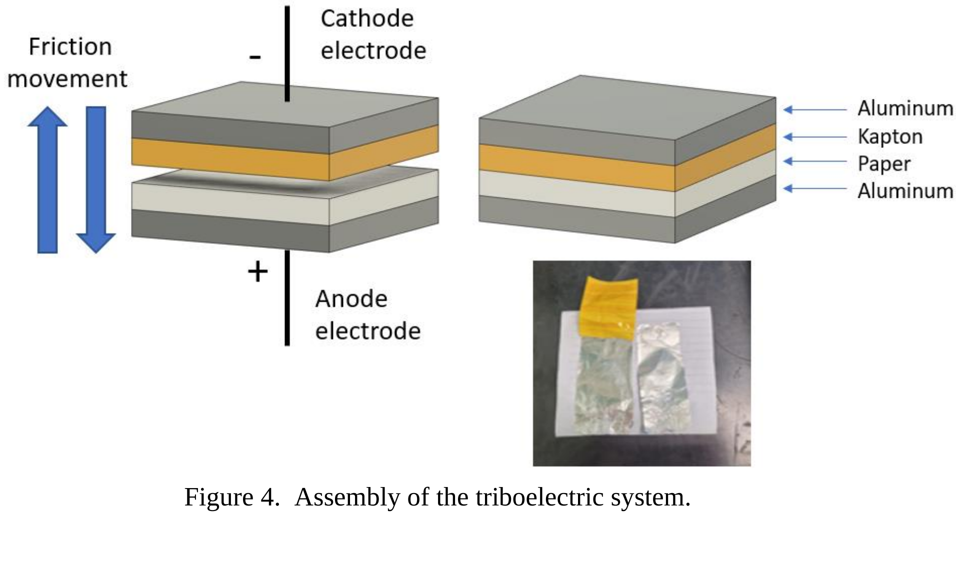


Figure 4. Assembly of the triboelectric system.

### 2.2 Piezoelectric materials

Within the piezoelectric system, a platform was built containing 12 piezo discs with a diameter of 27 millimeters connected in series. With this platform, energy generation will occur during the passage of a truck over it and is divided into two main stages: during the passage of the truck's wheels and during the inter-axle distance. During the wheel passage, the platform will generate energy from the mechanical deformation in the piezoelectric devices caused by the weight of the truck, while during the inter-axle distance, generation will be caused by the vibration of the vehicle's passage. Fig. 5 presents the piezoelectric platform that was manufactured. It was used a card board and a spring in it piezo disk, in order to improve the vibration.

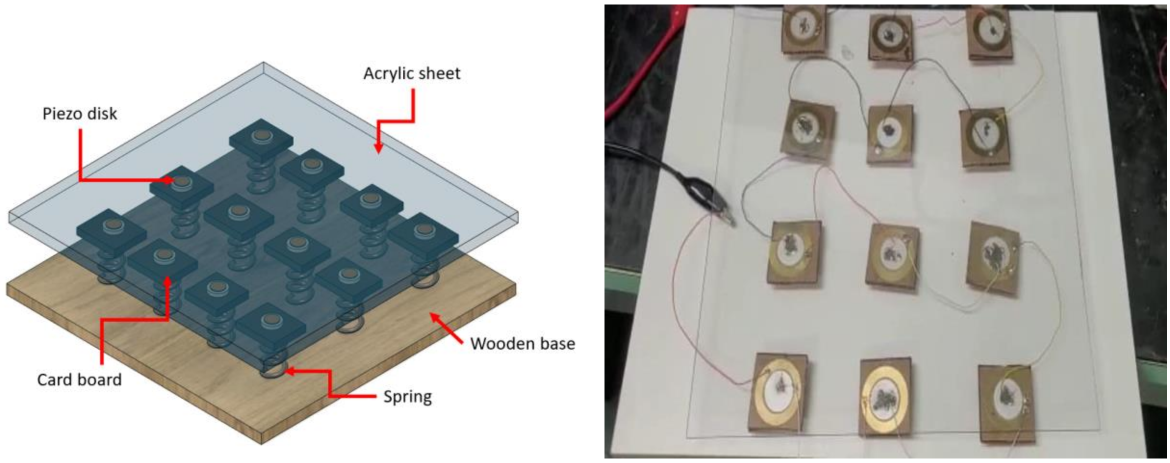


Figure 5. Piezoelectric platform.

In this method, reduced-scale tests were performed to observe the behavior of energy generation in the platform during mechanical deformation caused by the application of a weight force, simulating the truck's wheels. The combined weight of two people, totaling 150 kg, was used. It was observed that generation only occurs while there is movement on the platform, that is, during the entire wheel passage.

To analyze energy generation during the passage of the truck's inter-axle distance, tests were conducted by applying vibration only to the platform, without any weight on the acrylic plate. It was observed that the greater the vibration caused on the plate, the greater the generation will be.

### 2.3 Electromagnetic generators

In the system using electromagnetic generators, it was designed to simulate a speed bump with a rack connected below it. When a truck passes over it, the speed bump lowers, causing the rack to descend as well. This downward motion of the rack is crucial for initiating the energy generation process. As the rack descends, it engages with a set of gears, effectively transmitting the mechanical energy generated by the truck's weight to the generator system. The engaged gears form a mechanical linkage, transferring the rotational motion from the descending rack to the generator's shaft. Fig. 7 presents the proposed prototype.

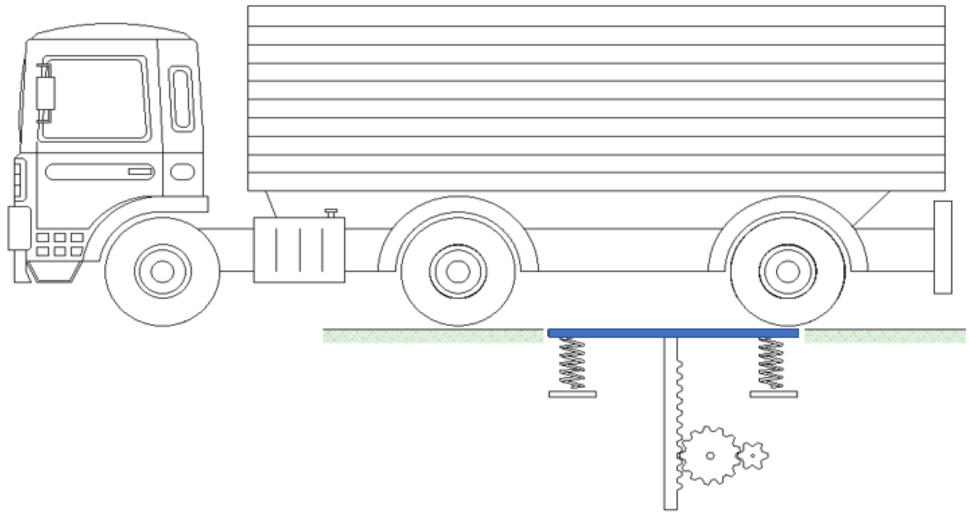

Figure 7. Scaled-down prototype of the mechanical speed bump system.

Fig. 7 presents the prototype of the mechanical speed bump system that was constructed. It was considered a spring with a value of 6500 N/m and a bearing model 608, with an external diameter of 22 millimeters and an internal diameter of 8 mm. The generator used in this prototype was a three-phase microgenerator with a rated power of 0.5/12 W. Fig. 7 presents the prototype of the mechanical speed bump system. In order to compeer the different energy harvesting method analyzed, it was also used the weight of two people, totaling 150 kg.

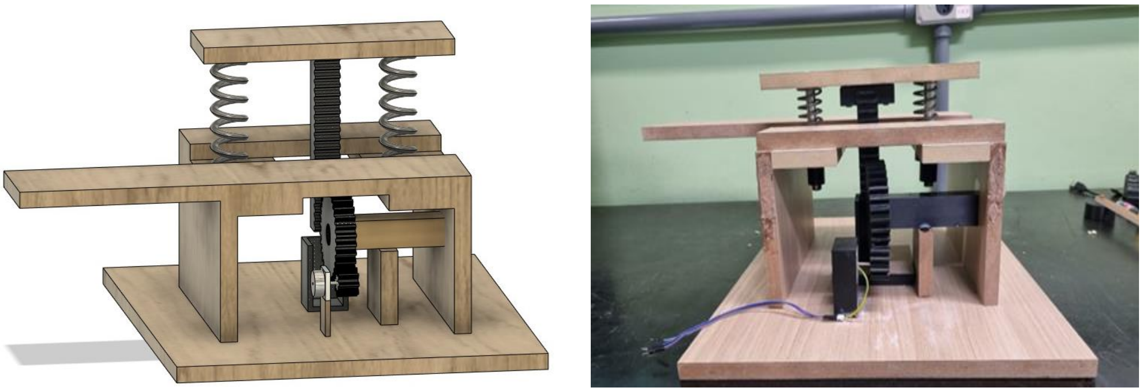

Figure 7. Scaled-down prototype of the mechanical speed bump system.

With the assembled prototype, the amount of energy generated was analyzed within the Material Test System (MTS) machine, which simulates compression on our prototype at different speeds. During the testing process, the MTS machine applied a compressive force to the prototype, replicating the mechanical stress that would be experienced when a vehicle passes over the system.

Figure 8. Material Test System (MTS) machine.

## 3. RESULTS AND DISCUSSION

Fig. 10 presents the results in a comparative chart of power generated per square meter. TENG generates 4V voltage, 82.6 µA $m^{-2}$ current, and 0.33 mW $m^{-2}$ output power over an area of 0.0121 $m^2$. Piezoelectric materials prototypes generate a voltage of 3.96V, a current of 18.5 µA $m^{-2}$, resulting in an output power of 0.073 mW $m^{-2}$. We utilized 12 piezo discs and two acrylic sheets, each with a surface area of 0.09 $m^2$. The electromagnetic generators prototype required an area of 0.0625 $m^2$ and generates a voltage of 2V, a current of 24 mA $m^{-2}$, resulting in an output power of 48 mW $m^{-2}$.

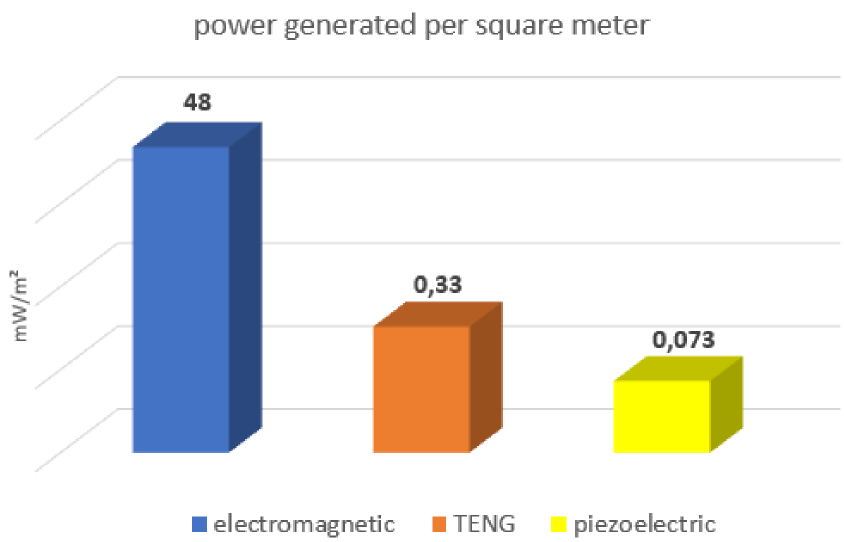

Figure 10. Comparative chart of power generated per square meter.

According to the cost-effectiveness, electromagnetic (around US$ 30) is three times more expensive than piezoelectric and TENG structures (around US$ 10). The electromagnetic generator, despite being the most expensive and requiring biannual maintenance, has the highest output power. The triboelectric generates the second-highest output power per unit area, while the piezo generates the least output power but is the cheapest. Although these methods have potential for harvesting energy from roads, further research is necessary to optimize their efficiency and cost-effectiveness

The electromagnet generator prototype was tested in the MTS machine that was set to operate at a frequency of 0.5 Hz. During the testing process, the MTS machine applied repeated compressions to the prototype at the specified frequency. As the prototype underwent compression, the mechanical energy was converted into electrical energy by the designated mechanism. Fig. 9 present the electric current behavior extracted for a respective movement extracted by the oscilloscope.

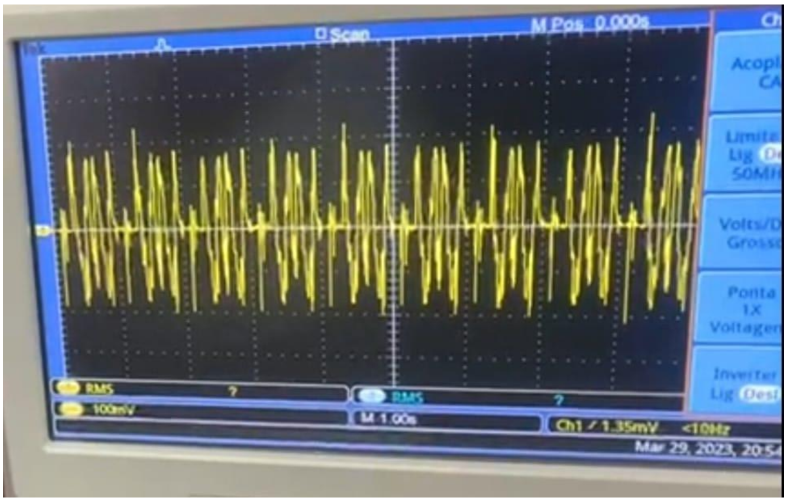


Figure 9. Signal obtained on the oscilloscope.

Another crucial factor to consider is the efficiency of energy conversion. Electromagnetic generators typically exhibit high conversion efficiency due to well-established principles of electromagnetic induction. Piezoelectric and triboelectric methods, however, may have lower efficiencies depending on factors such as material properties, environmental conditions, and design considerations. It's worth noting that advancements in materials and design techniques for piezoelectric and triboelectric generators continue to improve their efficiency and broaden their applications.

In summary, the choice of a power generation method depends on the specific requirements of the application, including power output, efficiency, and operating conditions. The electromagnetic generator offers higher power output and efficiency, making it suitable for larger-scale applications. The piezoelectric and triboelectric methods, although generating lower power, have their own advantages in terms of flexibility, scalability, and the ability to harvest energy from unique sources.

### 3.1 Electromagnetic generators calculations

Additionally, a spreadsheet was created containing the formulas and calculations used to mathematically model the system and simulate results with values closer to the operation of a real-scale prototype. First, the known measurements of the system were entered into the spreadsheet cells, such as the length and displacement (L) of the rack, the spring constant (K) with a value of 6500 N/m, the radius, module, and number of teeth of the gears, as well as some assumed values, such as the truck's mass (Pt) at 10000 kg and the number of axles (n) at 2, resulting in an axle mass (me) of 5000.

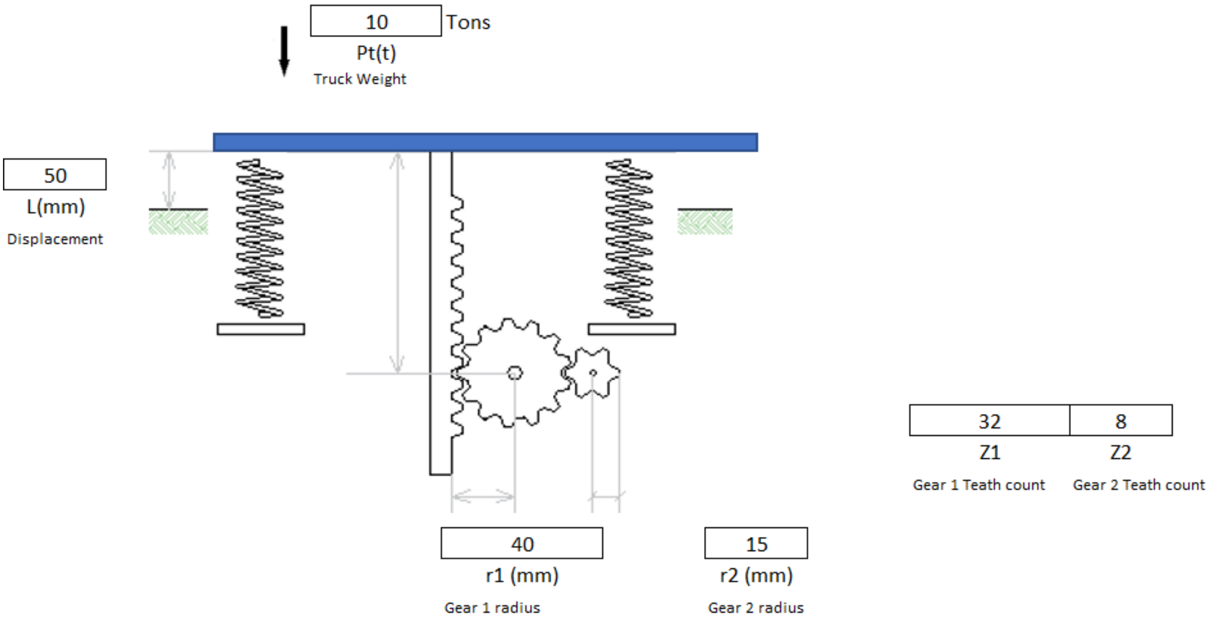


Figure 12. Representation of the mechanical speed bump system.

The known values of the system are as follows: the length of the rack is 100 mm, its displacement is 50 mm, the radius (r1), module (M), and number of teeth of the larger gear (Z1) are 40 mm, 3, and 32, respectively. In the smaller gear, which is connected to the generator shaft, the radius (r2) is 15 mm, the module (M) is 3, and it has 8 teeth (Z2). From the values of the gears, it was possible to obtain the gear ratio (i) of 40mm, which is determined by dividing the number of teeth of the larger gear by the number of teeth of the smaller gear, shown in Eq. (1).

$$i = \frac{Z_1}{Z_2} \tag{1}$$

Next, the diameter of the larger gear (D1) was calculated (96 mm) to determine the number of rotations that each gear performs. This was done by multiplying the number of teeth of the gear by its module, shown in Eq (2). Then, the gear's circumference (C1) was calculated by multiplying the gear diameter by π (pi), shown in Eq. (3). This value of C1=300mm will be used to calculate the number of rotations.

$$D_1 = Z_1 * M \tag{2}$$

$$C_1 = D_1 * \pi \tag{3}$$

By dividing the displacement of the rack by the circumference of the larger gear, it is possible to determine the number of rotations of that gear (N1=0.17 rotations), shown in Eq. (4). With this calculated, the number of rotations of the second connected gear (N2=0.7 rotations) can be determined, shown in Eq. (5).

$$N_1 = \frac{L}{C_1} \tag{4}$$

$$N_2 = N_1 * i \tag{5}$$

After knowing the number of rotations for each gear per pulse, the angular velocity of the motor shaft gear (w2) was calculated using the Eq. (6), resulting in 66 rads/s or 629 rpm.

$$w_2 = \frac{1}{r_2} * \sqrt{2 * g * L - \frac{K * L^2}{me}} \tag{6}$$

## 4. CONCLUSIONS

In conclusion, this article presented an experimental analysis of various energy harvesting sources for supplying power to road weighing systems. The study explored the effectiveness of triboelectric nanogenerators (TENG), piezoelectric materials, and electromagnetic generators. Considering cost-effectiveness, the electromagnetic generator proved to be the most expensive option, requiring biannual maintenance. However, it exhibited the highest output power among the three methods. The triboelectric generator ranked second in output power per unit area, while the piezoelectric generator was the most economical but generated less power.

Overall, this investigation contributes to the advancement of sustainable energy solutions by exploring various energy harvesting sources for road weighing systems. With continued research and development, these technologies have the potential to play a significant role in harnessing energy from roads efficiently and cost-effectively.

As the world strives towards a more sustainable future, it is vital to explore innovative approaches for energy generation. By integrating energy harvesting systems into our infrastructure, we can tap into the immense potential of our road networks to generate clean and renewable power. Continued advancements in energy harvesting technologies will pave the way for a greener and more efficient transportation system.

## 5. REFERENCES

[1] G. Liao, J. Xi. Design and Implement of Vehicle Dynamic Weighing System. Int. Conf. on Intelligent Computation Technology and Automation, pp. 1131-1134, 2010.

[2] Zh. A. Sukhinets; A. I. Gulin; A. N. Krasnov. Smart Dynamic Weighing System. International Conference on Industrial Engineering, Applications and Manufacturing (ICIEAM), 2020. DOI: 10.1109/ICIEAM48468.2020.9111892

[3] A. Suryana and M. S. Muntini, Strain gage for mass sensor using cantilever beam. Int. Conf. on Computing Engineering and Design, pp. 1-4, 2017.

[5] Fubing Han; Abdul W. Bandarkar; Yilmaz Sozer. Energy Harvesting from Moving Vehicles on Highways. IEEE Energy Conversion Congress and Exposition (ECCE), 2019. DOI: 10.1109/ECCE.2019.8912688

[6] S. Sudevalayam and P. Kulkarni, Energy harvesting sensor nodes: Survey and implications, IEEE Commun. Surveys Tuts., v. 13, no. 3, pp. 443-461, 3rd Quart 2011.

[7] Tom J. Kazmierski, Steve Beeby. Energy Harvesting Systems Principles, Modeling and Applications. Ed. Springer, 2011. DOI 10.1007/978-1-4419-7566-9

[8] Hao Wang, Abbas Jasim, Xiaodan Chen. Energy harvesting technologies in roadway and bridge for different applications – A comprehensive review. Applied Energy, n. 212, pp. 1083-1094, 2018. DOI: 10.1016/j.apenergy.2017.12.125

[9] Hiroyuki Akinaga. Recent advances and future prospects in energy harvesting technologies. Japanese Journal of Applied Physics, n. 59, 2020.

[10] Daewon Kim; Weon-Guk Kim; Ik Kyeong Jin; Hongkeun Park; Moo Jin Kwak; Sung Gap Im; Yang-Kyu Choi. Triboelectric energy harvester with an ultra-thin tribo-dielectric layer by initiated CVD and investigation of underlying physics in the triboelectricity. IEEE International Electron Devices Meeting (IEDM), 2016. DOI: 10.1109/IEDM.2016.7838485

[11] Soararn Kim; Yongchang Dong; Sean Gorman; Digangana Khan; Ferhat Bayram; Apparao M. Rao; Goutam KoleyMulti-mode Integrated Energy Harvester Utilizing Piezoelectricity and Triboelectricity. IEEE 13th Nanotechnology Materials and Devices Conference (NMDC), 2018. DOI: 10.1109/NMDC.2018.8605894

[12] D. Guyomar and M. Lallart, Recent progress in piezoelectric conversion and energy harvesting using nonlinear electronic interfaces and issues in small scale implementation, Micromachines, vol. 2, no. 2, pp. 274-294, 2011.

[13] Yasna Schifferli. Maximizing the energy harvested from piezoelectric materials for clean energy generation. IEEE Canada International Humanitarian Technology Conference (IHTC), 2017. DOI: 10.1109/IHTC.2017.8058178

[14] D. Hill, A. Agarwal and N. Tong, Assessment of piezoelectric materials for roadway energy harvesting: cost of energy and demonstration roadmap. California Energy Commission, 2014.

[15] S. Shevtsov, V. Akopyan, E. Rozkov, V. Chebanenko and I. Zhilyaev, Performance optimization of piezoelectric stack energy harvester. International Conference on Structural Engineering Dynamics ICEDyn 2015. DOI: 10.13140/RG.2.1.4589.8724

[16] H.C. Lin, P.H. Wu, I.C. Lien, Y.C. Shu. Analysis of an array of piezoelectric energy harvesters connected in series. Smart Materials and Structures, v. 22, pp. 1-11, 2013.

[17] Haocheng Xiong, Linbing Wang. Piezoelectric energy harvester for public roadway: On-site installation and evaluation. Applied Energy, v. 174, pp. 101-107, 2016. DOI: doi.org/10.1016/j.apenergy.2016.04.031.

## 6. RESPONSIBILITY NOTICE

The author(s) is (are) the only responsible for the printed material included in this paper.