

Design and Development of a Footstep-Based Electricity Generator Prototype Using Faraday's Law

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Abstract- The increasing demand for electrical energy and the environmental impacts of fossil fuel consumption encourage the exploration of renewable and alternative energy sources. One potential source of renewable energy is the mechanical energy generated from human activities such as walking. This study aims to design and develop a prototype device capable of generating electrical energy from footstep pressure by applying the principle of electromagnetic induction based on Faraday's Law. The prototype consists of a stepping platform equipped with springs, a coil system wound with enamel wire, a permanent magnet, and a measurement unit using a galvanometer. When a person steps on the platform, the spring mechanism causes the magnet to move relative to the coil, producing a change in magnetic flux that induces an electromotive force. Experimental observations indicate that faster oscillations of the spring result in larger galvanometer deflections, indicating higher induced current. The results demonstrate that the prototype successfully converts mechanical energy from footsteps into electrical energy. This device has potential applications as a small-scale renewable energy generator and as an educational tool for demonstrating electromagnetic induction principles.

Keywords: *Footstep energy harvesting; Faraday's law; electromagnetic induction; renewable energy prototype; mechanical-to-electrical energy conversion.*

1 Introduction

The global demand for electrical energy continues to increase significantly as a result of population growth, industrial development, and rapid technological advancement. Electricity has become an essential component in modern society because it supports various sectors such as transportation, communication, healthcare, education, and industry. However, the majority of electricity production worldwide still relies heavily on fossil fuels such as coal, petroleum, and natural gas. These energy sources are non-renewable and contribute significantly to environmental problems, including greenhouse gas emissions, air pollution, and climate change (Fitriani et al., 2018; Solikah & Bramastia, 2024). Consequently, the development of alternative and renewable energy sources has become an important research focus in recent decades. Renewable energy technologies offer a promising solution to reduce dependence on fossil fuels while supporting sustainable development. Various renewable energy sources such as solar energy, wind energy, hydropower, and geothermal energy have been widely explored and implemented in many countries. These energy sources are naturally available and environmentally friendly because they produce minimal pollution during operation. Wind and water energy, for example, are commonly used to generate electricity by converting kinetic energy into electrical energy through mechanical systems and generators (Andi Mulkan, 2022; Widodo et al., 2018). Despite their advantages, large-scale renewable energy systems often require substantial infrastructure and high installation costs, which can limit their accessibility in certain regions.

How to Cite

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In addition to natural energy resources, human activity itself represents a potential source of renewable energy that has not been fully utilized. Everyday human movements such as walking, running, or jumping generate mechanical energy that can potentially be converted into electrical energy using appropriate energy harvesting technologies. This concept has attracted increasing attention from researchers due to the high density of pedestrian activity in urban environments such as transportation hubs, shopping centers, public spaces, and university campuses. The large number of people moving through these locations provides an opportunity to harness mechanical energy generated from footsteps and convert it into useful electrical power (Ritonga, 2025).

Footstep energy harvesting systems are designed to capture the mechanical energy produced when a person steps on a surface and convert it into electrical energy using various energy conversion mechanisms. Several technologies have been explored for this purpose, including piezoelectric systems, hydraulic mechanisms, and electromagnetic induction systems. Among these technologies, electromagnetic induction is one of the most fundamental and widely used principles in electricity generation. This principle is based on Faraday's Law of electromagnetic induction, which states that a change in magnetic flux through a coil induces an electromotive force (EMF) within the conductor (Griffiths, 2013).

Faraday first discovered the phenomenon of electromagnetic induction in 1831, demonstrating that an electric current can be generated when a conductor experiences a changing magnetic field. This principle forms the theoretical foundation of many modern electrical devices, including generators, transformers, and induction motors (Cahyani, 2025). According to Faraday's Law, the magnitude of the induced electromotive force is proportional to the rate of change of magnetic flux passing through the coil. Mathematically, the induced voltage can be expressed as the negative rate of change of magnetic flux multiplied by the number of coil turns. The negative sign represents Lenz's Law, which states that the induced current always opposes the change in magnetic flux that produces it (Jati & Priyambodo, 2024). In the context of energy harvesting from footsteps, the electromagnetic induction principle can be applied by creating a system in which mechanical pressure causes relative motion between a magnet and a coil. When a person steps on a platform, the mechanical force compresses a spring mechanism that moves a magnet inside a coil. This movement changes the magnetic flux through the coil, inducing an electrical current that can be measured or stored for later use. The efficiency of such systems depends on several factors, including the number of coil windings, the strength of the magnetic field, the speed of motion, and the stability of the mechanical system. Several studies have investigated the feasibility of generating electricity from human footsteps using electromagnetic induction. For example, Kurniawan and Zulkifli (2019) developed a system that utilizes a solenoid coil and a neodymium magnet to convert foot pressure into electrical energy. Their results demonstrated that the movement of the magnet inside the coil produces a measurable electrical output, although the generated voltage remains relatively small. Similarly, Siregar and Sakti (2018) designed an electromagnetic induction trainer based on Faraday's and Lenz's laws to serve as a physics learning medium. Their work highlighted the potential of such systems as both energy harvesting devices and educational tools for demonstrating fundamental physics concepts.

Recent research has also explored the potential of vibration-based or motion-based energy harvesting technologies. Ahmad et al. (2024) investigated the use of mechanical vibrations as a source of electrical energy generation and concluded that motion-induced electromagnetic systems can serve as alternative energy solutions for small-scale applications. Other studies have emphasized the importance of optimizing system components, such as improving coil design, increasing magnet strength, and integrating energy storage devices such as capacitors or rechargeable batteries (Mahendra & Arif, 2024). These improvements can enhance the efficiency and practicality of footstep-based energy generation systems. Despite the promising potential of these technologies, several challenges remain in the development and implementation of footstep-powered electricity generators. One major challenge is the relatively low amount of electrical energy generated from a single footstep. Human footsteps typically produce small amounts of mechanical energy, which limits the electrical output unless the system is optimized or installed in locations with high pedestrian traffic. Another challenge involves the mechanical durability and stability

of the system, particularly the spring mechanism and structural components that must withstand repeated loads over long periods of use (Aryani et al., 2022).

In addition to technical challenges, there is also a need to increase public awareness regarding the potential of renewable energy sources derived from everyday activities. Many people are still unfamiliar with the concept of energy harvesting from human motion, even though it offers a simple and environmentally friendly way to generate electricity on a small scale. Implementing such technologies in public areas could not only contribute to energy generation but also serve as an educational tool that encourages society to adopt more sustainable energy practices.

Based on these considerations, this study aims to design and develop a prototype device capable of generating electrical energy from human footsteps using the principle of electromagnetic induction based on Faraday's Law. The prototype consists of a stepping platform supported by springs, a coil wound with enamel wire, and a magnet that moves vertically inside the coil when the platform is pressed. The induced electrical current generated by the system is measured using a galvanometer to evaluate the functionality of the device (Fauza, 2025).

The development of this prototype is expected to contribute to the exploration of alternative renewable energy technologies that utilize human activity as an energy source. In addition, the device can serve as an educational demonstration tool for illustrating the principles of electromagnetic induction in physics learning environments. By integrating simple mechanical and electrical components, this prototype demonstrates how basic physical principles can be applied to develop innovative solutions for sustainable energy generation. Ultimately, such technologies may support future developments in energy harvesting systems that are environmentally friendly, cost-effective, and adaptable to various public infrastructures.

2 Research Methodology

This study employed an experimental prototype development method to design and test a device capable of converting mechanical energy from human footsteps into electrical energy using the principle of electromagnetic induction. The research was conducted in the Physics Education Laboratory, Faculty of Teacher Training and Education, Universitas Riau, during the even semester of the 2024/2025 academic year. The experimental approach involved designing, constructing, and testing a prototype device to observe the conversion of mechanical energy into electrical energy based on Faraday's Law.

2.1 Prototype Design

The prototype was designed to transform mechanical pressure produced by a human step into vertical motion that changes the magnetic flux within a coil. The system consists of three primary components: a stepping platform, an electromagnetic induction unit, and a measurement system. Based on Figure 1, the device design consists of three main components:

1. Stepping platform, made of acrylic and equipped with four compression springs at each corner to allow vertical up-and-down motion.
2. Induction unit, consisting of a coil made from a PVC pipe wound with enamel copper wire. Inside the coil, a bar magnet moves up and down when the platform is stepped on.
3. Measurement system, used to detect the presence of generated electric current, where the galvanometer probes are connected to the coil wires.

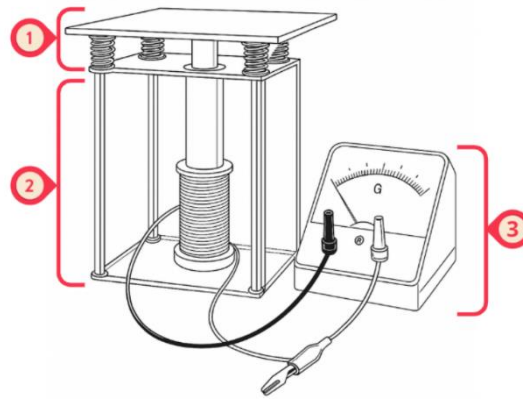


Figure 1. Design of a Power Generator from Footsteps

The stepping platform is constructed from an acrylic plate supported by four compression springs placed at each corner. The springs allow the platform to move vertically when a force is applied by a user's foot. This vertical motion drives the movement of a magnet that is attached to a metal rod connected to the stepping plate.

The second component is the electromagnetic induction unit, which consists of a cylindrical coil made by winding enamel copper wire around a PVC pipe. The coil is positioned directly beneath the magnet so that the magnet moves inside the coil when the platform is pressed. This relative motion between the magnet and the coil produces a change in magnetic flux within the coil.

The third component is the electrical measurement system. The ends of the coil wire are connected to a galvanometer or LED indicator to detect the presence of induced electrical current. The galvanometer provides a visual indication of current generation by showing needle deflection whenever a step is applied.

2.2 Materials

The materials used to construct the prototype include enamel copper wire with a diameter of 0.7 mm, acrylic sheets with a thickness of approximately 0.2 cm, a cylindrical PVC pipe with a diameter of $\frac{3}{4}$ inch, compression springs made of stainless steel wire, a permanent bar magnet, adhesive glue, and connecting wires with crocodile clips. Tools used in the construction process include a jigsaw machine, drilling machine, scissors, and measurement instruments.

2.3 Prototype Construction Procedure

The construction process began with the fabrication of the electromagnetic coil. A PVC pipe with a length of approximately 21 cm was prepared as the core of the coil. Circular acrylic plates were attached to both ends of the pipe to serve as the coil frame. The enamel wire was then wound around the pipe to form multiple layers of coil windings. In this prototype, approximately 160 turns were wound in each layer, with a total of about seven layers, resulting in approximately 1120 turns of wire.

After completing the coil assembly, the structural frame of the device was constructed using acrylic sheets to form a rectangular enclosure measuring approximately 13 cm \times 10 cm \times 21 cm. The coil assembly was mounted vertically inside this frame. Next, the stepping platform was fabricated from a square acrylic plate measuring approximately 19 cm on each side. A metal rod was attached to the center of the plate, and a permanent magnet was fixed at the lower end of the rod so that it could move vertically inside the coil. Four compression springs were installed between the frame and the stepping plate to allow controlled oscillatory motion.

2.4 Working Principle of the Device

The operation of the device is based on electromagnetic induction according to Faraday's Law. When a person steps on the platform, the compression springs are pressed downward, causing the magnet

attached to the rod to move inside the coil. This movement changes the magnetic flux through the coil windings.

According to Faraday's Law, a change in magnetic flux induces an electromotive force (EMF) in the coil. This induced voltage causes an electric current to flow through the circuit, which can be observed through the deflection of the galvanometer needle. When the stepping force is released, the springs return the magnet to its original position, creating another change in magnetic flux and generating additional induced current. This oscillatory motion allows the system to repeatedly generate electrical energy from successive footsteps.

3 Results and Discussion

Prototype Development Results

The prototype of the footstep electricity generator was successfully designed and constructed according to the planned configuration. The device consists of a stepping plate mounted on springs, a vertical magnet motion system, and a coil unit connected to a galvanometer for electrical detection.

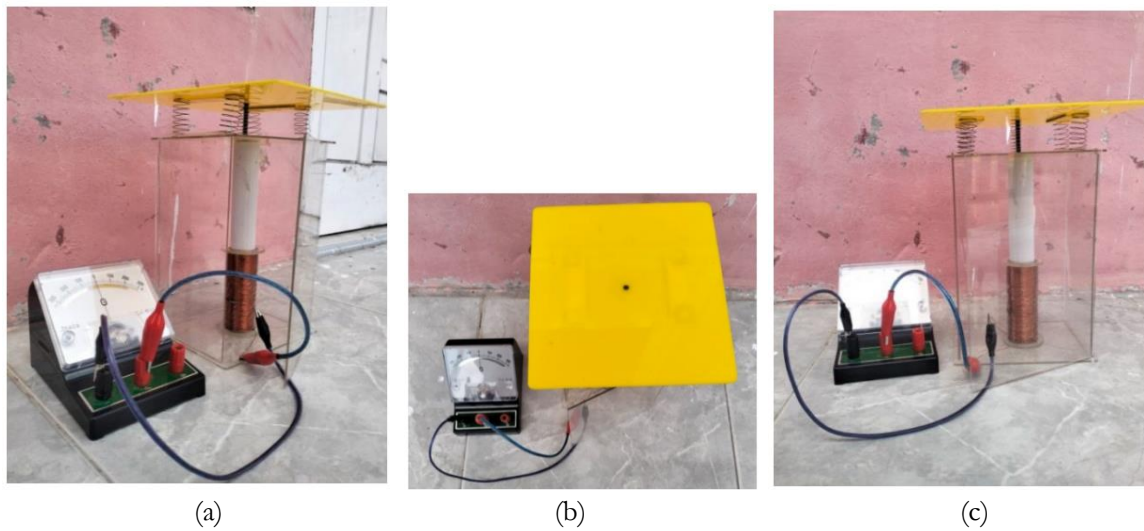


Figure 2. Footstep-Based Electricity Generator Prototype
(a) Side view, (b) Front view, (c) Top view

The physical structure of the prototype shows a transparent acrylic frame that houses the coil and magnet system. A yellow stepping plate is positioned at the top of the device and supported by compression springs. When pressure is applied to the plate, the springs compress and cause the magnet to move vertically inside the coil. The coil is connected through wires to a galvanometer, which displays the electrical current generated during operation.

Experimental Observation

Experimental observations were conducted by pressing the stepping platform at different speeds to examine the relationship between spring oscillation speed and the magnitude of induced current. The primary indicator used in the experiment was the deflection of the galvanometer needle. The experimental observations are summarized in Table 1

Table 1. Relationship Between Spring Oscillation and Galvanometer Response

Spring Oscillation Speed	Galvanometer Needle Movement
Slow	Small deflection
Moderate	Moderate deflection
Fast	Large deflection

The results show that the movement of the galvanometer needle becomes larger as the oscillation speed of the spring increases. This indicates that a faster movement of the magnet within the coil produces a greater change in magnetic flux, resulting in a larger induced electromotive force.

Discussion

The experimental results confirm that the prototype operates according to the principle of electromagnetic induction described by Faraday's Law. When the magnet moves inside the coil due to the stepping motion, the magnetic flux through the coil changes over time. This change in magnetic flux induces an electromotive force in the coil that generates an electrical current. The magnitude of the induced current depends on several factors, including the speed of magnet movement, the strength of the magnetic field, and the number of coil windings. In this prototype, approximately 1120 turns of copper wire were used to increase the sensitivity of the system. Increasing the number of coil windings increases the induced voltage because the induced electromotive force is proportional to the number of turns in the coil.

The use of compression springs plays a crucial role in the operation of the device. The springs allow the magnet to move downward when pressure is applied and return to its original position after the force is released. This oscillatory motion ensures that magnetic flux changes occur repeatedly, allowing continuous induction of electrical current during repeated footsteps.

Although the prototype successfully demonstrates the conversion of mechanical energy into electrical energy, the electrical output produced by the system remains relatively small. The current generated is only sufficient to move the galvanometer needle and cannot yet power electronic devices. This limitation is primarily due to the relatively small mechanical energy produced by a single footstep and the limited efficiency of the prototype system. Despite this limitation, the prototype provides valuable insight into the potential of human motion as a renewable energy source. If installed in areas with high pedestrian traffic such as railway stations, airports, stadiums, or shopping centers, similar systems could collectively generate a measurable amount of electrical energy. In addition, integrating energy storage components such as capacitors or rechargeable batteries could enable the storage and accumulation of electrical energy produced by multiple footsteps.

Another advantage of this device is its educational value. The prototype serves as an effective demonstration tool for teaching fundamental physics concepts such as electromagnetic induction, energy conversion, and harmonic motion. By observing the movement of the galvanometer needle during operation, students can directly visualize the relationship between mechanical motion and electrical energy generation. Overall, the results demonstrate that the prototype successfully converts mechanical energy from human footsteps into electrical energy through electromagnetic induction. Although further optimization is required to increase energy output, the system provides a promising foundation for the development of footstep-based energy harvesting technologies and educational physics equipment.

4 Conclusion

This study successfully designed and developed a prototype device capable of generating electrical energy from human footsteps by applying the principle of electromagnetic induction based on Faraday's Law. The prototype consists of a stepping platform supported by compression springs, a coil system wound with enamel copper wire, a permanent magnet that moves vertically inside the coil, and a measurement unit connected to a galvanometer. The system operates by converting mechanical energy from human footsteps into electrical energy through changes in magnetic flux within the coil.

The experimental observations demonstrate that the prototype is able to produce an induced electric current when the stepping platform is pressed. The compression of the springs causes the magnet to move relative to the coil, resulting in a change in magnetic flux that induces an electromotive force according to Faraday's Law. The galvanometer needle deflection observed during testing confirms the generation of electric current. Furthermore, the results show that the magnitude of the induced current depends on the speed of the spring oscillation. Faster stepping motion leads to a greater rate of change in magnetic flux, which in turn produces a stronger induced current.

Although the electrical output produced by the prototype remains relatively small and is currently only detectable through a galvanometer, the device effectively demonstrates the feasibility of converting human mechanical energy into electrical energy. This finding highlights the potential of footstep-based energy harvesting systems as an alternative renewable energy source, particularly in locations with high pedestrian traffic such as transportation terminals, public facilities, and university campuses. In addition to its potential application in renewable energy technology, the developed prototype also provides significant educational value. The device can be used as a practical teaching aid for demonstrating fundamental physics concepts, including electromagnetic induction, energy conversion, and harmonic motion. Future development of this system could focus on improving energy efficiency by optimizing coil design, increasing magnet strength, and integrating energy storage components such as capacitors or rechargeable batteries. With further improvements, this technology has the potential to contribute to sustainable energy solutions and innovative physics learning tools.

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