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Experimental and Factor Analysis on a Novel Wave Energy Generator Using Electromagnetic Induction

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

Amidst global concerns over escalating energy consumption and environmental pollution, wave energy has garnered substantial interest. However, its commercial viability has remained questionable. This research introduces an innovative wave energy conversion method employing electromagnetic induction, aiming to evaluate its potential to elevate wave energy into a prominent renewable source. Through quantitative simulation of a self-built prototype and factor analysis, the study identifies key factors influencing energy harvesting efficiency. The research unveils that the speed of the magnet has minimal influence on energy generation, reinforcing the consistency of the new device. Notably, rotational wave movements exhibit superior energy harvesting, providing insights for optimizing wave energy converters. The findings suggest a potential for consistent energy outputs, irrespective of wave strength, opening new avenues for the commercialization of efficient wave energy technology.

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Keywords: Electromagnetic induction; factor analysis; sustainable energy; wave energy generator.

1. INTRODUCTION

The current global energy demand and the urgent need to combat the emissions responsible for climate change have spurred a quest for alternative and sustainable energy sources. Conventional fossil fuels have long been the primary energy source, but their utilization has led to detrimental environmental repercussions such as air pollution and the exacerbation of the greenhouse effect [1]. NASA claimed that the combustion of fossil fuels "increased the level of atmospheric carbon dioxide [2,3]. As a result, scientists have started to investigate several forms of renewable and sustainable sources.

Sustainable energy is defined as any energy source that cannot be depleted and can remain viable forever [4]. It does not require to be renewed or recharged; sustainable energy satisfies our demand for energy without any feasibility of going rotten or running out [5-7]. This is the reason that sustainable energy is the best replacement for our energy demands. Furthermore, sustainable energy doesn't cause any harm to the environment, or at most, there is a minimal risk of triggering the increase in climate change, or cost a heavy price. Although a cost is associated with creating and building ways to collect sustainable energy, the energy sources themselves are typically free [8]. Various examples of renewable energies, including solar, wind, geothermal, biomass, and others, have long been discussed. Recently, however, wave energy has emerged as a promising source in this conversation, sparking the debate of whether it is effective [9,10-12].

Wave Energy refers to the form of power generated by the movement of waves, considered to be a promising source of clean and sustainable power with the potential to contribute to the global energy mix [13,14-17]. Harvesting wave energy involves Wave Energy Converters (WECs), designed to capture and convert the kinetic and potential energy present in ocean waves into practical forms of electricity. This energy travels across all ocean expanses in the form of waves, creating a powerful and continuous source of renewable energy. Potential energy possessed by wave could be calculated by the following generalized formula [4,18-20]:

$$P = \frac{\rho g^2}{64\pi} H^2 T \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

where ρ is sea water density $1.03\, g/cm^3$, gravitational acceleration g = $9.81\, m/s^2$, significant wave height H, and wave period T. Since ρ, g, π are constants, the only variables that are relevant in assessing wave potential energy are significant wave height H and wave period T.

Various types of wave energy converters that transform this wave potential energy into practical electricity have been employed. The two most commonly used WECs are point absorbers and oscillating water columns [21]. Point absorbers are usually two-body: a floating buoy that captures the wave energy, and the other is attached to the seafloor that serves as the converter. The floating platform moves with the motion of the waves, causing the mechanical motion to be converted into electrical power [22]. Oscillating Water Columns use the rise and fall of the water levels in a chamber to generate air movements, which drive a turbine connected to a generator. Both WECs have a commonality in the fact that they are dependent on the motion of the waves [22].

Wave energy possesses a series of benefits that are distinctive from other renewable energy. Primarily, wave energy is globally available to most nations as oceans cover about 71% of the Earth’s surface. This energy accessibility makes wave energy a potentially widespread and scalable energy solution. As confirmed by George Lavidas’ study, many regions in Greece have achieved the desired significant wave height and wave period that could produce usable electricity outputs. While these results are only applicable to Greece, Lavidas still justifies that wave energy could be a vast and untapped resource for everyone in the world [23]. Also, waves are a perpetual source. As long as wind patterns exist, wave energy can be continuously harnessed without depleting the source.

However, although the wave is a continuous quality, it may provide inconsistent outputs, as the magnitude of waves varies by weather conditions. David Levitan states that wave energy has far lagged behind other renewables due to its inefficiency and inconsistency dependent on weather, specifically wind, which has been a theme of experts for three decades. Robert Thresher in the National Renewable Energy Laboratory maintains that the best wave energy device may not have even been invented

[24]. Moreover, Sunghoon Hong and his colleagues at Busan University, Korea, claimed that irregular waveforms cause significant wave heights to fluctuate, ultimately making it difficult to establish a fixed type of wave energy converter that could efficiently harvest electricity [22]. These insights from experts prove that wave energy has a long way to go to be commercially viable.

Even though recent assessments of wave energy are depressing, this does not entirely discredit wave energy's potential. Different research from George Lavidas with Vengatesan Venugopal claims that moderate wind regions with low significant wave height (H) can also be resourceful, with the selective use of supervising tools [25]. Even though a specific solution has not been mentioned, they demonstrate that wave energy research is still abeyant. Therefore, this research delved into the field of wave energy, hoping to provide a more ingenious wave energy converter.

First, the most consequential drawback of wave energy is its inconsistency. Currently, wave energy converters depend on the wave's strength, which is determined by the wind that is out of human control [24]. Due to its dependence on weather conditions, wave energy has not been as practical contrary to Solar or Wind Energy. Therefore, instead of using a wave as a force to spin the turbine, a different force was needed to convert the wave potential to electricity. After careful deliberation, incorporating electromagnetic induction in wave energy harvesting would result in more consistent outputs since electromagnetic force is not primarily correlated with movements.

Electromagnetic induction plays a pivotal role in this study's novel approach to wave energy conversion. This fundamental principle of electromagnetic induction involves generating an electromotive force (EMF) or voltage in a conductor when exposed to a changing magnetic field. The crucial part of electromagnetic induction is the changing magnetic field, where the magnet needs to be constantly moving. In the context of wave energy, the ocean wave will be moving the magnet within a coil, with a changing magnetic field inducing an electric current on it.

The significance of electromagnetic induction lies in its capacity to provide a consistent and predictable energy source, regardless of the speed or strength of the wave. Unlike traditional wave energy converters that are heavily dependent on the force of the waves, electromagnetic induction offers a unique advantage by decoupling the energy generation process from the unpredictable and fluctuating nature of wave strength. This independence from wave characteristics enhances the potential for reliable and continuous energy output, marking a significant step towards addressing the historical challenges associated with the intermittency and inconsistency of wave energy sources.

If electromagnetic induction is conducted, the resultant will be an electromotive force (EMF) at first, alternately known as induced voltage. Faraday's Law of Induction gives the magnitude of emf (ε):

$$\varepsilon = -N\frac{d\phi}{dt} \text{…………… (2)}$$

$\frac{d\phi}{dt}$ denotes the rate of change of magnetic flux over time. The negative sign in the equation supports the direction of the induced current according to Lenz's law, stating that the induced current will flow in a direction that is negative to the change in magnetic flux [26]. As noticed, no variables related to acceleration or external force demonstrate that electromagnetic induction is independent of wave movements. This proves that theoretically, voltage and energy generated from electromagnetic induction are independent of any outside environment, shedding light on new potential alternatives for wave energy harvesting.

To reconcile the existing flaws in wave energy converters, this study would determine how to stabilize and maximize the electricity outputs of wave energy harvested by the novel wave energy generator that uses electromagnetic induction to enhance commercial uses in retrospect of wave energy. The Research Question for my study was: What strategies can be employed on a novel electromagnetic induction-based wave energy converter to enhance the commercial viability of wave energy? By addressing this question, it will effectively assess whether the incorporation of electromagnetic induction in wave energy will be an effective alternative and reconcile the gap of inconsistency and commercial availability. Our hypothesis was that the new prototype incorporating electromagnetic induction should be able to address the gap of inconsistency since it is theoretically independent of the outer environment.

2. METHODS

Due to time and monetary restrictions, the study was conducted as a simulation experiment with a self-built prototype. As large-scale devices and financial support were required for real-time testing on waves, the prototype was moved by hand to simulate ocean wave movements on the device. Although some limitations come with a simulation, this method makes the experimental process more practical while acquiring data and drawing reasonable results through adequate experimental procedures.

2.1 Materials and Electric Parts

While the prototype was relatively simplistic, it still required core elements to simulate wave energy accurately. Building components such as coils, containers, magnets, and data acquisition devices was crucial in acquiring and analyzing data.

2.1.1 Data acquisition system

The data should be quantitatively analyzed through appropriate software to analyze the power outputs and the consistency of the wave energy outputs. The device used to acquire data is the Model DI-2008, shown in Fig. 1. DI-2008 is the thermocouple and voltage acquisition device, and in my experiment, it would be used to capture the necessary electrical outputs generated by the electromagnetic force.

DI-2008 also has compatible software, WinDAQ, which is free and accessible for high school students and Windows users. When DI-2008 captures the electrical data, WinDAQ makes it into a user-accessible form for Data Analysis. In particular, WinDAQ makes the output of electromagnetic induction into a Power vs. Time Graph, which is an easier form of analyzing energy harvested.

Moreover, in WinDAQ software, various statistical measurements are given in the Statistics section. Some trivial variables include Maximum, Minimum, and variance. The Area Under the Curve (AUC) was one crucial variable used throughout the study. The Area Under the Curve of Power (P) vs. Time Graph gives the electrical energy of the system in Joules (J), as shown below:

$$AUC = \int_{t_1}^{t_2} P(t)dt = U\ (Joules)\ldots\ldots\ldots\ldots\ldots \quad (3)$$

AUC was a more effective variable for assessing both the outputs and consistency, as it gives the cumulative electric energy throughout the given period, unlike one-point values such as maximum and minimum.

2.1.2 Coils and containers

Initially, the optimal design for the wave energy converter was considered, and various shapes were tested. These designs were not prototypes but explorations to determine the most effective configuration. Small-scale devices were constructed to compare their energy outputs. The first consideration was a flat disk with magnets rolling on the surface. However, this design resulted in insignificant outputs, measuring induced voltage below 1 Volt. Recognizing the need for a more efficient shape, the next consideration was a cylindrical tube with a magnet rolling inside. This design produced a substantial output of approximately 5 Volts, making it a promising candidate.

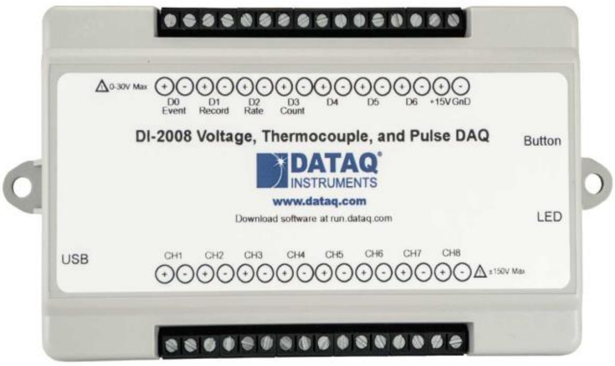

Fig. 1. Picture of Model DI-2008

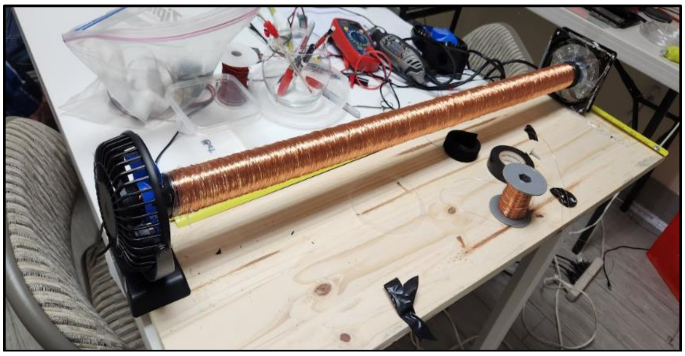

Fig. 2. Picture of coil-wounded wave energy generator bars

Fig. 3. Strong neodymium magnets were used in the experiment

Upon comparing the flat open disk with the enclosed cylindrical tube, Our hypothesis was that the energy outputs would be greater if the magnet were enclosed within surfaces in all directions. Subsequently, a flat box-like container with magnets inside was implemented. Surprisingly, this structure resulted in induced voltage below 1 Volt, contrasting with the earlier success of the cylindrical tube.

While this outcome seems surprising, it aligns with scientific laws and the researcher's findings. Cylindrical Design maximizes the value N in Faraday's law of Induction, which is the density of the coil. Compared to other designs like disk or box, the cylinder maximizes the density with the least amount of coils, proposing the most economical prototype. Other researchers also have aligned beliefs that a cylindrical tube is the most effective device to induce voltages. N.P. Georgiev and R.P. Raychev also used a roughly cylindrical model to justify their study model of linear generators for wave energy. Georgiev and Raychev claim that covering the surface of the magnet is crucial in maximizing the electricity outputs, as it causes the most interaction between the electric and magnetic fields [27].

Taking these into consideration, the wave energy converter was designed as an 80-centimeter plastic cylinder. For the Coil, 28 American Wire Gauge (AWG) of 2120 feet (about 646 meters) was used to evenly wrap the coil around the cylinder. Fig. 2 shows the self-designed prototype.

2.1.3 Super strong neodymium magnets

The selected magnet, the "Applied Magnets Super Strong Neodymium Magnet" is one of the world's strongest rare earth magnets. The magnet is manufactured in state-of-the-art ISO-certified facilities to ensure maximum quality. The product includes one Neodymium Rare Earth Permanent Magnet Sphere with a Grade N52 Magnetic Energy, possessing the title of the strongest ceramic magnet. They are also triple-layer coated for maximum durability and protection against corrosion.

Not only is it the strongest, but also it is the most effective in energy conversion. Bhupathi Raja and his colleagues demonstrated the effectiveness of neodymium magnets in energy conversion [28], which made me decide that

Neodymium magnets would be suitable for addressing the drawbacks of efficiency in traditional wave energy converters.

2.2 Experimental Procedure

With the built coiled cylindrical device, the study will be conducted with three combined stages. First, with the magnet moved inside the device, the induced electricity will be quantified through the Data Acquisition device, DI-2008. After the quantification, the output from DI-2008 is connected to the computer and analyzed through WinDAQ software. The process of the combined system is shown in Fig. 4 .

On WinDAQ software, the power output is shown in a waveform with respect to time. The real-time output sample screen on WinDAQ is shown in Fig. 5.

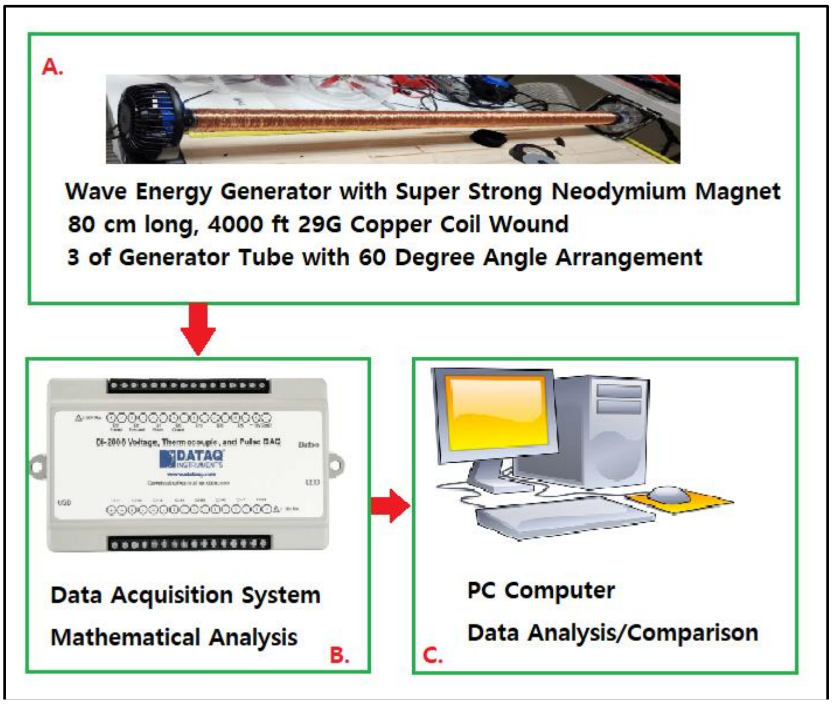

Fig. 4. Visual representation of the experimental procedure

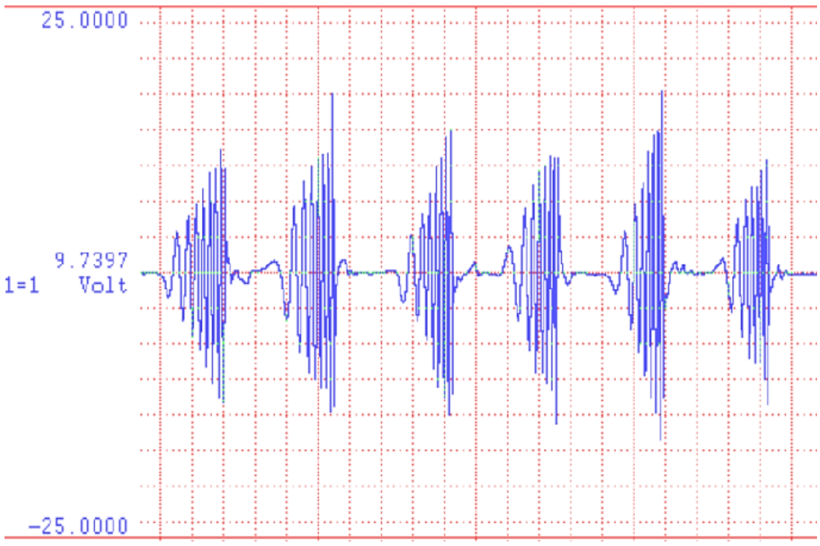

Fig. 5. Sample waveform from WinDAQ software

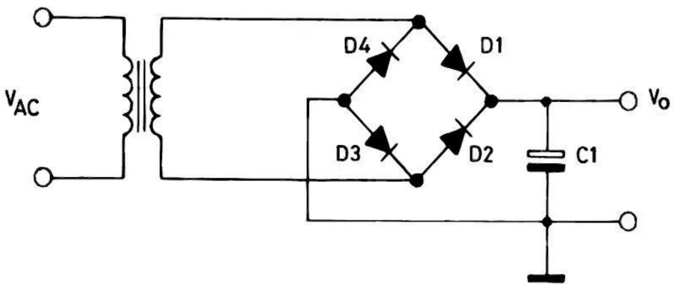

Fig. 6. Rectifier circuit diagram

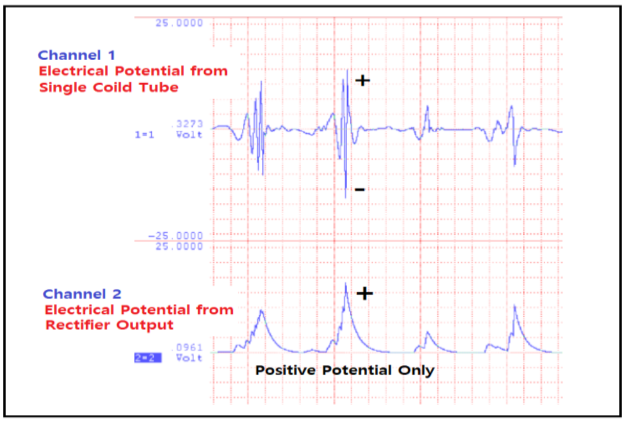

Fig. 7. Real-time screen for comparison between the AC and DC after the rectifier is used

However, as shown in Fig. 5, the voltage outputs occasionally dip into negative values, with continuing alteration in signs. This is called the Alternating Current (AC). The electromagnetically induced currents are AC, where electrons constantly change the direction of motion. While AC is the raw form of electricity, it cannot be practically practical. This is because AC changes its direction of flow therefore it charges and discharges the energy at the same time, converging the total electrical energy to 0. On the other hand, there is a form of Direct Current (DC), where the electrons' direction is constant throughout the system. For the storage of electricity, such as batteries, DC is used since it only requires charging. Therefore, an extension is needed with a converting device called a rectifier.

A rectifier, a device where it converts the alternating current (AC) to direct current (DC), was designed as a circuit. The design of the circuit used is shown as follows in Fig. 6.
In Fig. 6, C1 represents the Capacitor; the more capacitors the circuit has, the more "flat" the voltage output gets, meaning that voltage gets more stabilized and consistent. A capacitor wasn't used for this experiment's circuit as it is unnecessary for the energy charging procedure. The power output after going through a capacitor is contrasted with the previous output in Fig. 7.

For Channel 1, positive and negative voltages coexist; however, after the rectifier output, the output only gives positive electric potential, meaning the system has achieved direct current (DC).

Personal Protective Equipment (PPE), such as safety goggles and gloves, was used for safety purposes. Moreover, the strong magnet was carefully managed; it was removed from any magnetically sensitive instruments and devices after being used. Multiple magnets should not be stored close to each other since separating them later can hurt; therefore, each magnet was stored in boxes labeled clearly.

3. RESULTS

3.1 Estimation of Generating Electric Power by Magnet's Movements

As a wave collides with the device, the magnet inside the tube is moved. In this section, the study is trying to identify the relationship between electrical energy and power and whether they are proportional to the magnet's movements or velocity. This establishment will confirm whether this device has the potential to reconcile the gap of inconsistency by determining its relationship between wave speed and strength.

The device's steepness altered the magnet's velocity with respect to the sea level. As the device gets steeper about the sea level, the component of the gravitational acceleration acting on the magnet increases, causing the magnet's acceleration to increase. The angle θ is defined to be the angle between the device and the sea horizon, shown in the diagram below.

This section will investigate calculations and graphs for three general types of movement (fast, medium, and slow). Based on these sample calculations, additional data will be collected to conduct a correlational study and conclude whether electric energy is relevant to the speed of magnets.

3.1.1 Fast speed of movement angle (θ) of 45° or greater

For the first experiment, the experiment demonstrated a magnet's fast speed with a rotating angle of 45° or greater. The device was "rotated" 10 times, with each rotation defined as a magnet moving from each end of the device.

The total time taken for ten cycles was 11.7 seconds. The measured value of time and length of the device (80 cm) states that the average speed through the ten rotations is 0.68 m/s, calculated as below:

$$v_{avg} = \frac{total\ displacement}{time} = \frac{.8\ m \times 10}{11.7\ s} = .68\ m/s$$

For the speed of $.68\ m/s$, the electrical energy (area under the curve) was $14.84\ J$, shown in Appendix A. The Power vs. Time graph of such is displayed in Fig. 9.

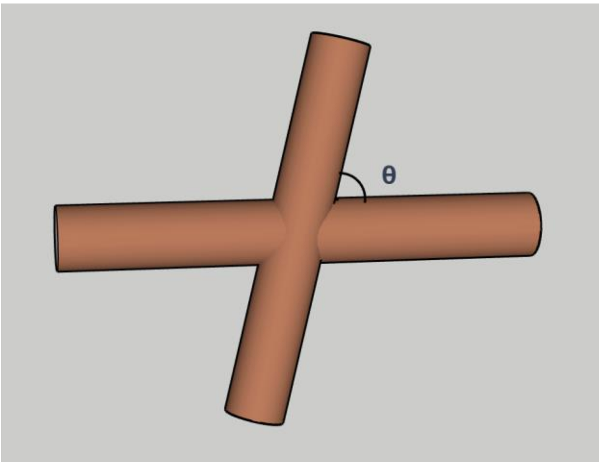

Fig. 8. Presentation of the simulational movement of the prototype

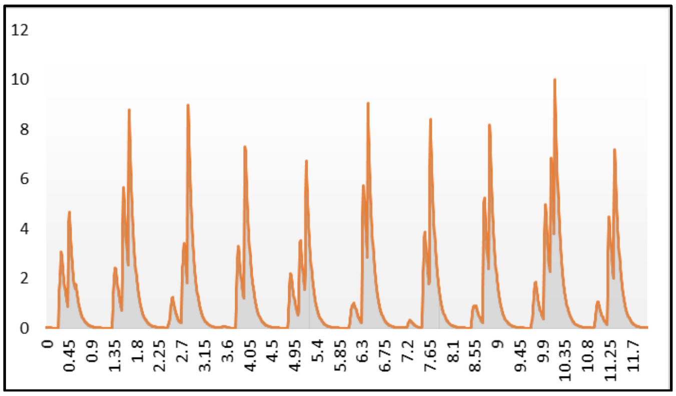

Fig. 9. Power vs. time graph for fast speed magnet movement

3.1.2 Medium speed of movement angle (θ) between 20° to 45°

Similarly, the total time taken for ten cycles was 13.52 seconds for the medium speed. As the displacement of the magnet is constant at 8 meters, the average velocity of the magnet is 0.59 m/s, calculated as below:

$$v_{avg} = \frac{total\ displacement}{time} = \frac{8\ m}{13.52\ s} = .59\ m/s$$

For the speed of $.59\ m/s$, the electrical energy (area under the curve) was $23.73\ J$, shown in Appendix B. The Power vs. Time graph of such a situation is displayed in Fig. 10.

3.1.3 Slow speed of movement angle (θ) below 20°

For the slow speed category, the total time taken for ten cycles was 21.56 seconds. As the displacement of the magnet is constant at 8 meters, the average velocity of the magnet is 0.59 m/s, calculated as below:

$$v_{avg} = \frac{total\ displacement}{time} = \frac{8\ m}{21.56\ s} = .37\ m/s$$

For the speed of $.37\ m/s$, the electrical energy (area under the curve) was $23.10\ J$, shown in Appendix C. The Power vs. Time graph of such a situation is displayed in Fig. 11.

3.1.4 Replication and discussion

To derive conclusions about the relationship between the speed of magnetic and electrical energy, more than 3 data were needed to generalize the results. Therefore, 12 additional data were collected, making up a total of 15 data. More data collection was needed to reasonably conclude the relationship between the two variables. With the new data, a correlational study was conducted to see how relevant the two variables are in context. The data was collected and analyzed using the same methods as in previous sections. The following graph shows the correlational study:

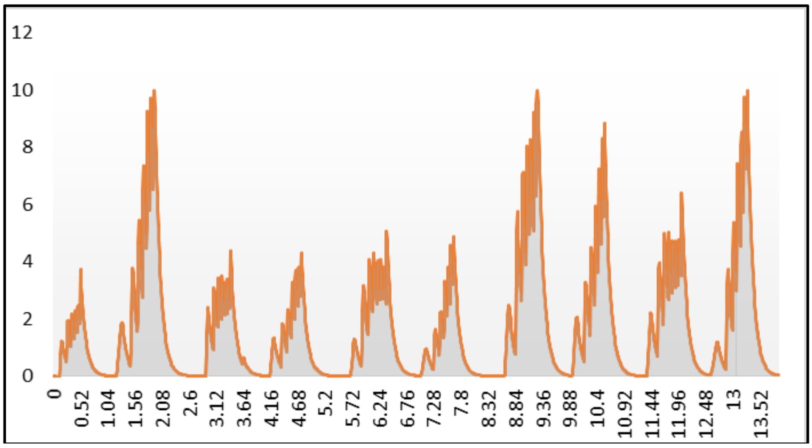

Fig. 10. Power vs. time for medium speed magnet movement

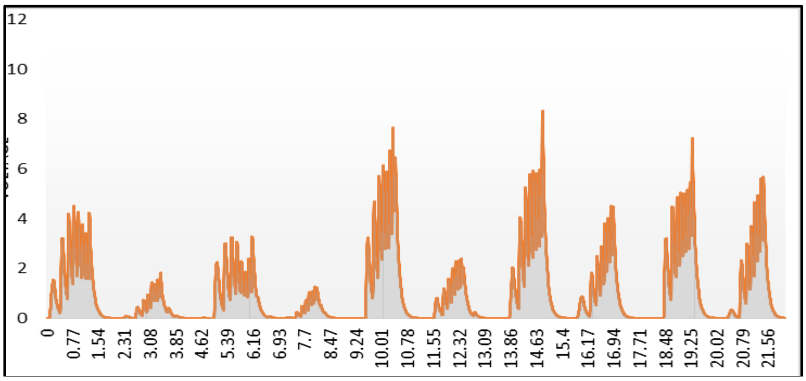

Fig. 11. Power vs. time graph for slow-speed magnet movement

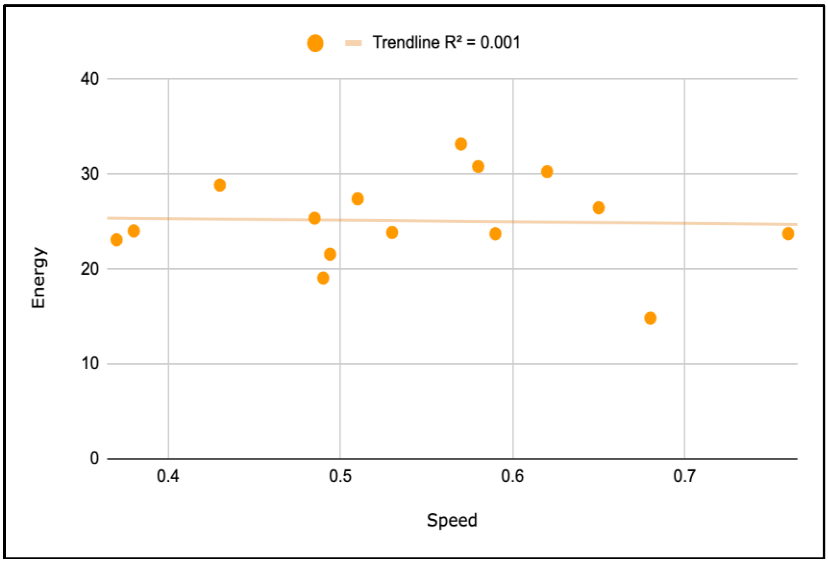

Fig. 12. Correlational study on energy and speed

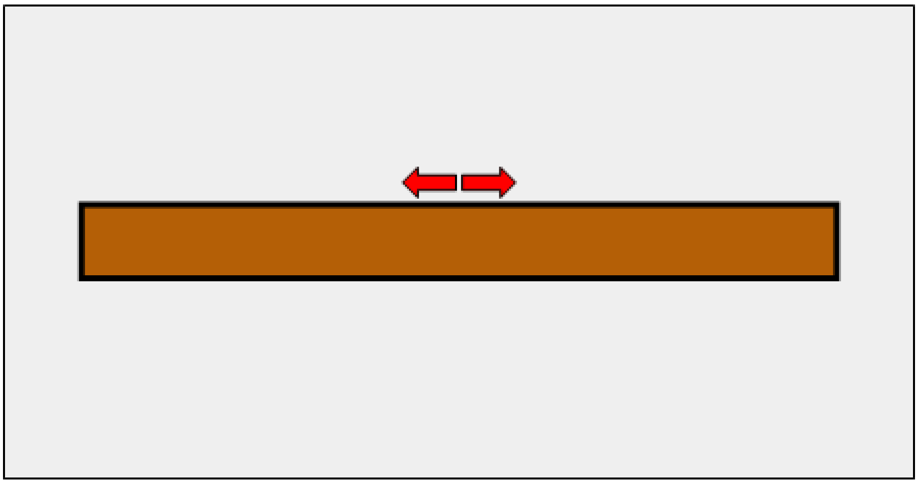

Fig. 13. Visual representation of the device in linear horizontal movement

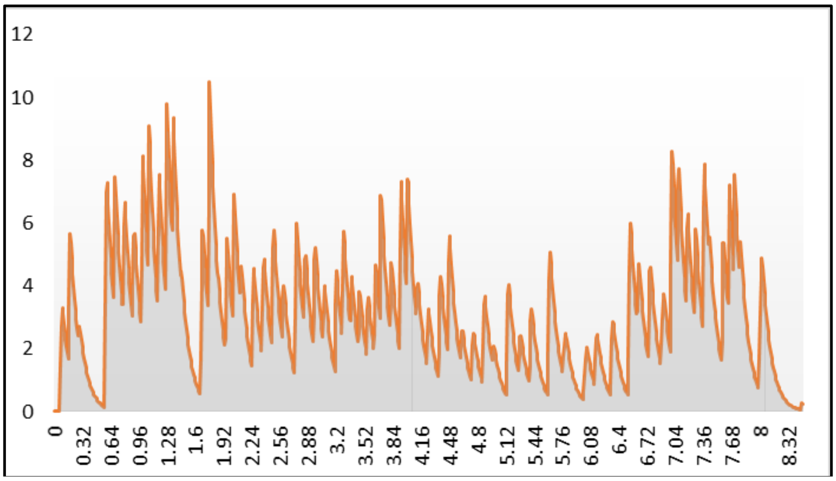

Fig. 14. Power vs. time graph for linear horizontal movement

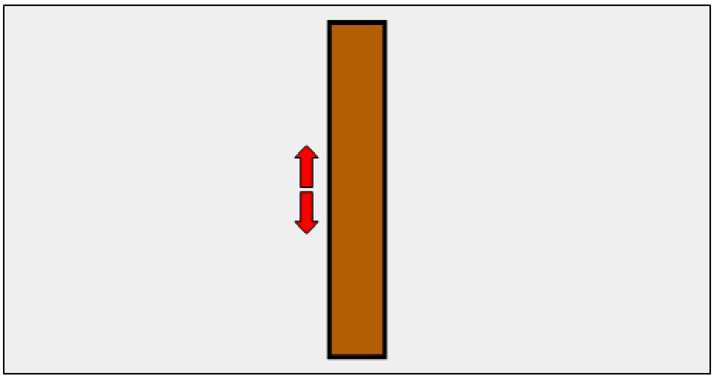

Fig. 15. Visual representation of the device in linear vertical movement

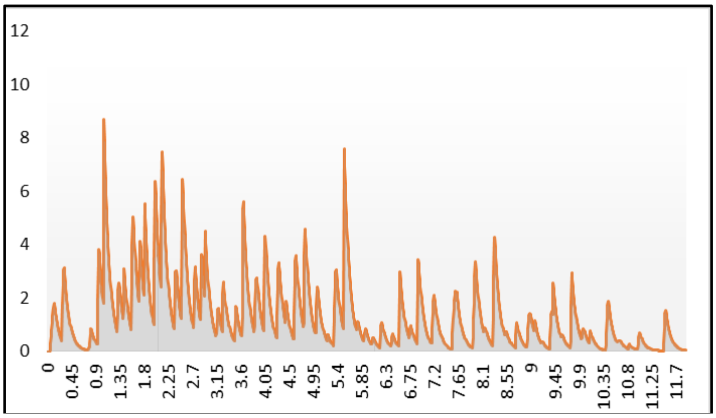

Fig. 16. Power vs. time graph for linear vertical movement

Surprisingly, the collected data on Energy and Speed showed a correlation of almost zero with an R-value of -0.038. As the R-value of 0 represents no correlation, it demonstrates that the relationship between Energy and Speed is weak, showing there is almost no relationship.

3.2 Estimation of Generating Electric Power by Classifications of Wave Forms

As a wave is a three-dimensional continuous motion, many waveforms exist. In Environmental Science, the waves of earthquakes, known as Seismic waves, are usually classified into four categories: P-waves and S-waves, Rayleigh-waves, and Love-waves. Inspired by this, the sea waves were categorized into four movements: Linear Horizontal, Linear Vertical, Rotational, and Oscillatory movements.

3.2.1 Linear horizontal wave movements

Linear Horizontal Wave Movement is defined as horizontal movement parallel to the ground. To test linear horizontal movement, the device was shaken right and left, maintaining its parallel position with the ground. It was shaken 20 times, keeping the period as constant as possible. A period is defined as a magnet returning to the point at which it started. Following is the Power vs. Time Graph for the Linear Horizontal Wave Movement.

3.2.2 Linear vertical wave movements

Linear Vertical Wave Movement is defined as vertical movement perpendicular to the ground. To test Linear Horizontal Movement, the device was shaken up and down, maintaining the device perpendicular to the ground. It was shaken 20 times, keeping the period as constant as possible. A period is defined as a magnet returning to the point at which it started. Following is the Power vs. Time Graph for the Linear Vertical Wave Movement.

The harvested Electric Energy was $26.9\,J$ from linear vertical movement, shown in Appendix D.

The harvested Electric Energy was $15.8\,J$ from this movement, shown in Appendix E.

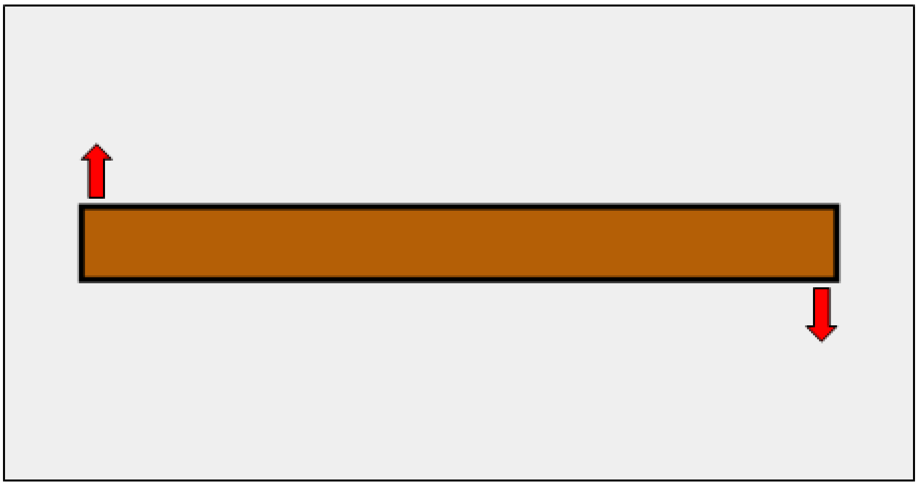

Fig. 17. Visual representation of the device in rotational movement

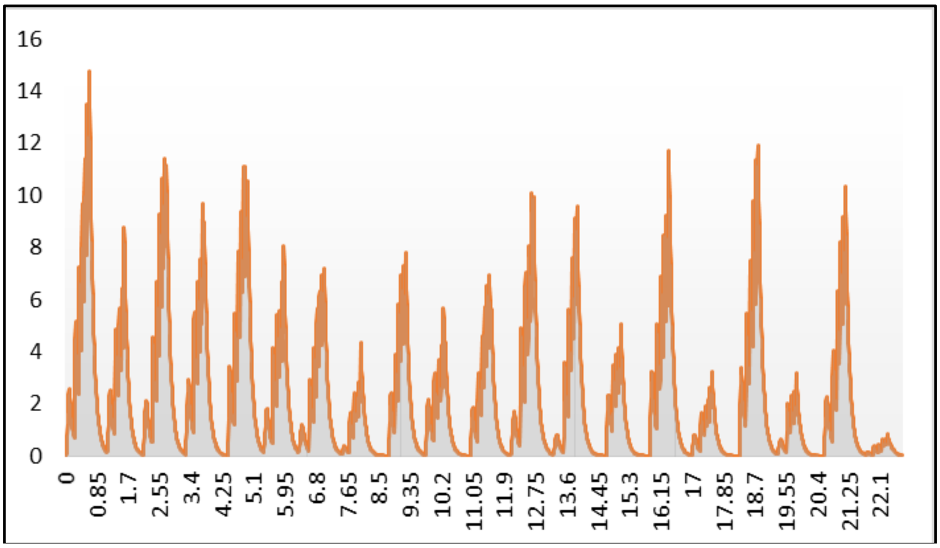

Fig. 18. Power vs. time graph for rotational movement

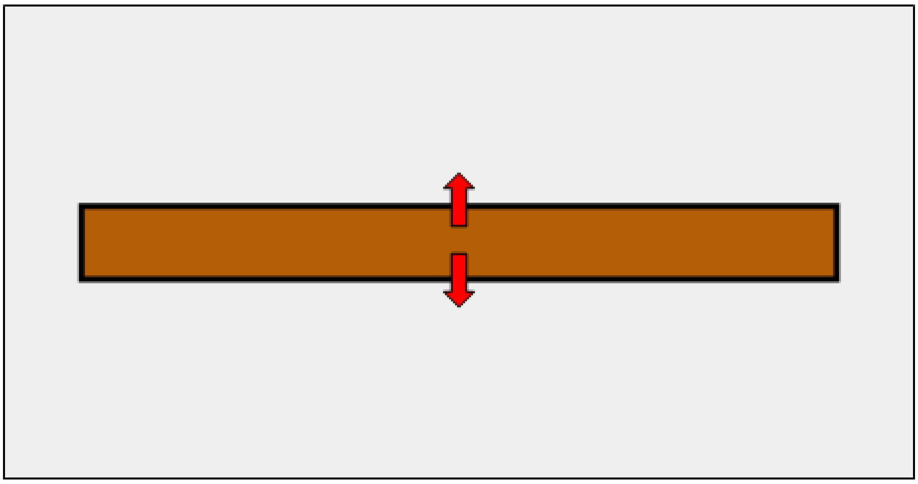

Fig. 19. Visual representation of the device in oscillatory movement

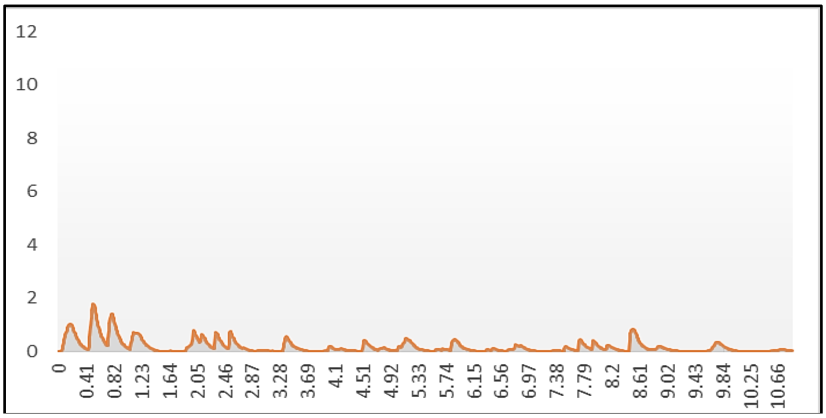

Fig. 20. Power vs. time graph for oscillatory movement

3.2.3 Rotational wave movements

Rotational Wave Movement is defined as the angular movement of each tip oscillating simultaneously, causing the device to rotate back and forth partially. The device was rotated with an angle to test Rotational Movement, just as in section 3.1. It was shaken 20 times, keeping the period as constant as possible. A period is defined as a magnet returning to the point at which it started. Following is the Power vs. Time Graph for the Rotational Wave Movement.

In the following movement, the harvested Electric Energy was $49.7\,J$, shown in Appendix F.

3.2.4 Oscillatory wave movements

Oscillatory Wave Movements are defined as movement along the cross-section of the cylinder. To test Rotational Movement, the device was shaken so that the magnet was not displaced along the device. It was shaken 20 times, keeping the period as constant as possible. A period is defined as a magnet returning to the point at which it started. Following is the Power vs. Time Graph for the Oscillatory Wave Movement.

In the following movement, the harvested Electric Energy was $1.85\,J$, shown in Appendix G.

4.DISCUSSION

4.1 Implications

Data collected in Section 3.1 demonstrates that the movements of the magnet are not correlated with the Electric Energy. This result seems reasonable because the slower the magnet, the longer the time acted with the electromagnetic system. Therefore, it can be concluded that the harvested wave energy from this novel device is not relevant to the speed of the magnet, raising questions on other areas to explore.

This discovery that energy is irrelevant to the speed of a magnet shows the bright side: The prototype utilizing a magnet is not dependent on wave strength, which means it could provide consistent outputs independently from weather conditions. This resolves the experts' ongoing concern about existing wave energy converters that cannot offer long-term consistent outputs. However, as a magnet is not correlated with electric energy output, the question regarding efficient harvesting still needs to be answered.

Therefore, the second variable approached was energy outputs in different types of waveforms. As mentioned, motivated by Seismic waves, ocean waves were classified into four waveforms: Linear Horizontal, Linear vertical, Rotational, and Oscillatory. While the portion of such movements can differ, the fluid motion will be broadly explained in those four motions.

The collected data shows that Rotational wave movements were most effective in harvesting electric energy $(49.7\,J)$, with almost double the energy of other movements. On the other hand, oscillatory movement, with an electric energy of $1.85\,J$, demonstrated negligible contribution to the generation of energy. Therefore, rotational wave movements and minimal oscillatory wave movement should be employed to maximize electric energy. This points to the question: what variables would be relevant in maximizing the rotational wave movement? Answering this question will be crucial in the commercialization of wave energy.

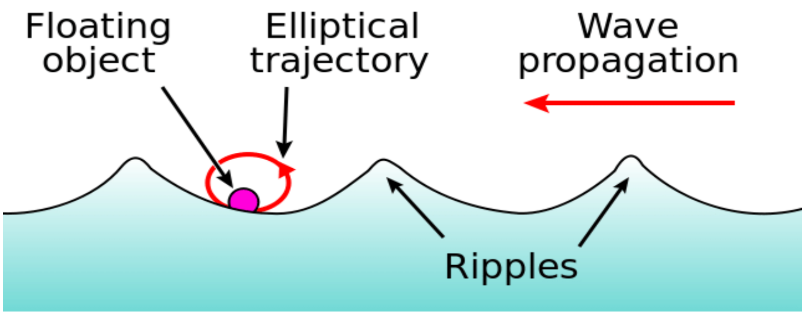

Fig. 21. Trajectory of a floating object on waves

One suggestion is to keep the device intact with the wave surface. As stated before, a wave combines the above four movements. As the wave propagates horizontally and vertically on the water surface, the floating object will maintain an elliptical trajectory, as shown in Fig. 21. The device will not be going through perfectly circular motion as the horizontal and vertical movement rates will diverge. Nonetheless, keeping the device on the wave surface will effectively replicate a rotational movement, giving the maximum electric energy.

Another implication would be the device's placement with respect to the direction of the wave. As oscillatory movement barely influences the electrical energy output, it should be minimized to have significant outputs. Therefore, when the device is placed, wave movements should not act perpendicular to it. Rather, wave propagations should hit the device in parallel so that it harvests horizontal and rotational movement.

Therefore, this research gives insights into the practicality of the novel method and how it should be applied in the situation to harvest energy and get a step closer to commercialization successfully.

4.2 Limitations

This research has given valuable insights into the wave energy industry. However, certain limitations need to be acknowledged.

Firstly, the study relies on a self-built prototype for simulation experiments. This prototype, while serving the purpose of testing feasibility, lacks the professionalism and precision that might be achieved with more advanced and technical equipment. The constraints from time and limited background further this limitation, preventing immediate real-life applications. Consequently, the results should be interpreted cautiously, recognizing the inherent challenges in replicating the oceanic wave movements within a simulated experiment. Furthermore, the research fails to incorporate the economic analysis and viability of the proposed method. The transition from a simulated prototype to a commercially deployable technology demands a further understanding of the challenges and opportunities in scaling up the design, ensuring durability, and meeting industry standards.

Moreover, the research acknowledges the need for further exploration into the relationship between the speed of the magnet and electricity generation. The surprising finding that energy output is barely correlated with magnet speed raises questions about the factors influencing the efficiency of the proposed wave energy converter. However, while the study established no correlation, it does not conclude that the magnitude of the ocean wave does not influence the energy at all.

Additionally, the classification of waveforms into Linear Horizontal, Linear Vertical, Rotational, and Oscillatory movements provides a useful framework, but it oversimplifies the three-dimensional and dynamic nature of ocean waves. Ocean waves are three-dimensional and complex, and their classification might not fully capture the nuanced movements that influence energy harvesting. The study emphasizes the maximizing of rotational wave movements, but applying and achieving this in real-world conditions may require more in-depth analysis, addressing the varying nature of wave patterns.

In conclusion, while the study introduces a promising insight for wave energy conversion, the limitations of using a self-built prototype, the oversimplification of wave dynamics, and the need for further exploration into relevant variables underscore the preliminary nature of the findings. Future research should address these limitations for a more comprehensive understanding of the proposed wave energy conversion method.

5. CONCLUSIONS

In summary, this research aimed to assess the feasibility of wave energy conversion using electromagnetic induction, addressing key questions about the commercial viability of this approach. The study first recognized existing literature about the global interest in wave energy as a renewable source and acknowledged the uncertainties regarding its commercial application. The primary questions were whether electromagnetic induction could be a viable method for wave energy conversion and what factors influenced its efficiency. Through the analysis of a self-built prototype, the study explored the practicality and implications of the novel device.

The research found that the speed of the magnet had minimal influence on energy generation, challenging traditional expectations. The independence from the magnet's speed shows this prototype's potential to reconcile the gap of inconsistency. Moreover, this outcome prompted a deeper exploration of other variables, categorizing waveforms into Linear Horizontal, Linear Vertical, Rotational, and Oscillatory movements. The results highlighted that rotational wave movements were the most effective in harvesting electric energy, while oscillatory movements contributed negligibly. These findings provide crucial insights into the dynamics of wave motion and emphasize the importance of maximizing rotational movements for optimal energy harvesting.

In conclusion, while the research acknowledges the limitations associated with a self-built prototype that lacks professionalism, it provides valuable information to wave energy conversion. The results regarding the speed of the magnet confirm the device's potential to address the gap of consistency, and the emphasis on rotational wave movements opens new areas for exploration and optimization. The study sets the stage for future research to refine the proposed method to address limitations and move toward practical and economically viable wave energy solutions. Despite the challenges, the potential for consistent energy outputs and wave strength independence suggests a promising future for harvesting wave energy through electromagnetic induction.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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APPENDIX

APPENDIX A

Statistics Tab for file "fast speed" on WinDAQ Software
UNITS "Volt"
CHANNEL # 2
OF POINTS 1201
MEAN 1.23583E+00
STD DEVIATION 1.79558E+00
MINIMUM -2.13623E-02
MEDIAN 3.67737E-01
MAXIMUM 9.99969E+00
RMS 2.17915E+00
SUM 1.48423E+03
SUM OF SQUARES 5.70317E+03
VARIANCE 3.22409E+00
SKEWNESS 1.45039E+00
SLOPE 1.78460E-02
AREA 1.48423E+01
START POINT TBF 8.960
END POINT TBF 20.960
FILE fastspeed.WDH

APPENDIX B

Statistics Tab for file "medium speed" in WinDAQ Software
UNITS "Volt"
CHANNEL # 2
OF POINTS 1421
MEAN 1.67023E+00
STD DEVIATION 2.09260E+00
MINIMUM -1.92261E-02
MEDIAN 8.26721E-01
MAXIMUM 9.99969E+00
RMS 2.67685E+00
SUM 2.37340E+03
SUM OF SQUARES 1.01822E+04
VARIANCE 4.37896E+00
SKEWNESS 1.20927E+00
SLOPE 5.49143E-02
AREA 2.37340E+01
START POINT TBF 8.640
END POINT TBF 22.840
FILE mediumspeed.WDH

APPENDIX C

Statistics Tab for file "slow speed" in WinDAQ Software
UNITS "Volt"
CHANNEL # 2
OF POINTS 2209
MEAN 1.04578E+00
STD DEVIATION 1.45649E+00
MINIMUM -2.89917E-02
MEDIAN 3.04260E-01
MAXIMUM 8.32153E+00

RMS 1.79278E+00
SUM 2.31013E+03
SUM OF SQUARES 7.09984E+03
VARIANCE 2.12136E+00
SKEWNESS 1.52734E+00
SLOPE 3.09512E-02
AREA 2.31013E+01
START POINT TBF 9.440
END POINT TBF 31.520
FILE slow speed.WDH

APPENDIX D

Statistics Tab for file "linear horizontal" in WinDAQ Software
UNITS "Volt"
CHANNEL # 2
OF POINTS 861
MEAN 3.12475E+00
STD DEVIATION 1.95092E+00
MINIMUM 3.05176E-03
MEDIAN 2.89307E+00
MAXIMUM 1.05026E+01
RMS 3.68317E+00
SUM 2.69041E+03
SUM OF SQUARES 1.16801E+04
VARIANCE 3.80610E+00
SKEWNESS 3.56265E-01
SLOPE -2.00218E-01
AREA 2.69041E+01
START POINT TBF 2.570
END POINT TBF 11.170
FILE linearhorizontal2.WDH

APPENDIX E

Statistics Tab for file "linear vertical" in WinDAQ Software
UNITS "Volt"
CHANNEL # 2
OF POINTS 1201
MEAN 1.31935E+00
STD DEVIATION 1.31409E+00
MINIMUM -2.13623E-02
MEDIAN 8.95691E-01
MAXIMUM 8.66852E+00
RMS 1.86175E+00
SUM 1.58454E+03
SUM OF SQUARES 4.16278E+03
VARIANCE 1.72684E+00
SKEWNESS 9.67196E-01
SLOPE -1.72886E-01
AREA 1.58454E+01
START POINT TBF 7.310
END POINT TBF 19.310
FILE linearvertical.WDH

APPENDIX F

Statistics Tab for file “rotational” in WinDAQ Software
UNITS "Volt"
CHANNEL # 2
OF POINTS 2300
MEAN 2.16369E+00
STD DEVIATION 2.56168E+00
MINIMUM -2.28882E-02
MEDIAN 1.13831E+00
MAXIMUM 1.47476E+01
RMS 3.35275E+00
SUM 4.97649E+03
SUM OF SQUARES 2.58542E+04
VARIANCE 6.56222E+00
SKEWNESS 1.20084E+00
SLOPE -8.77751E-02
AREA 4.97649E+01
START POINT TBF 2.770
END POINT TBF 25.760
FILE rotational.WDH

APPENDIX G

Statistics Tab for file “oscillatory” in WinDAQ Software
UNITS "Volt"
CHANNEL # 2
OF POINTS 1089
MEAN 1.69918E-01
STD DEVIATION 2.60388E-01
MINIMUM -2.13623E-02
MEDIAN 6.56128E-02
MAXIMUM 1.78070E+00
RMS 3.10824E-01
SUM 1.85040E+02
SUM OF SQUARES 1.05210E+02
VARIANCE 6.78018E-02
SKEWNESS 1.20172E+00
SLOPE -3.44442E-02
AREA 1.85040E+00
START POINT TBF 2.260
END POINT TBF 13.140
FILE oscillatory.WDH

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