Empowering Sustainability: The Promise of Energy Harvesting from Wheel Motion (Experiment and simulation)

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Abstracts: The evident rise in the demand for durable and environmentally friendly power solutions in the future has spurred the advancement of inventive energy harvesting architectures, specifically emphasizing renewable sources such as wind and solar power. This study aims to make a valuable contribution to the field of energy harvesting by introducing an original concept: the utilization of energy generated from wheel motion. The proposed method involves strategically positioning magnets and copper coils inside the hubcap's spoke. As the wheel rotates, the magnets' movement induces a winding action within the coils. This dynamic interaction, in accordance with Faraday's Law, generates an electric current within the coil. To assess the effectiveness of this approach, a meticulously designed experimental setup was implemented, measuring the output voltage of the electromagnetics. These measurements provide significant insights into the energy harvesting potential of this method. Furthermore, to ensure the reliability and accuracy of the findings, a numerical simulation was conducted, enabling a comprehensive analysis and validation of the experimental results. By exploring the concept of wheel motion energy harvesting, this research strives to contribute to the development of sustainable and efficient power generation solutions. The integration of electromagnetic principles into this innovative approach highlights the viability of utilizing wheel motion as a practical energy source. These findings pave the way for further advancements in energy harvesting technologies, fostering a more sustainable and environmentally friendly future.

Keywords: Harvesting Energy, Magnet Movement Inside the Coil, Faraday Law, Spoke of Hubcap in Wheel.

1. INTRODUCTION

The growing demand for long-lasting power solutions in the future underscores the importance of developing new energy harvesting technologies. This has led to a significant increase in the number of articles and research studies dedicated to this field. Historically, energy harvesting methods have relied on wind (windmills), water (turbines), and solar power. However, with the current focus on clean energy to reduce fuel consumption and protect the environment, it is crucial to organize and classify alternative energy sources. Common types of energy harvesting devices include piezoelectric devices, mechanical vibration devices, thermoelectric generators, and electromagnetic generators, among others. This paper will focus on electromagnetic energy as a potential source. To fully comprehend the concept of electromagnetic energy harvesting, it is essential to first have a clear understanding of electromagnetism and its principles. By exploring electromagnetic energy harvesting, this research aims to contribute to the ongoing efforts in developing sustainable and efficient power solutions. Understanding the principles of electromagnetism will provide a solid foundation for exploring the potential of electromagnetic energy harvesting as a viable and environmentally friendly method for meeting future energy demands.

1.1 Electromagnetic Energy Harvesting

Electromagnetic induction, a groundbreaking discovery made by Michael Faraday in 1831, revolutionized our understanding of electricity generation. It involves the generation of an electric current within a conductor when it is exposed to a changing magnetic field. This principle forms the foundation of various energy harvesting technologies. In the context of energy harvesting, a coil is utilized as the conductor. By altering the magnetic field or repositioning a magnet in relation to the coil, electrical energy can be produced. The amount of energy generated depends on several factors, including the strength of the magnetic field, the speed at which the magnetic field changes, and the characteristics of the coil itself. The relationship between these factors is crucial in determining the efficiency and output of the energy harvesting system. A stronger magnetic field, faster movement speed, and a well-designed coil can result in higher energy generation. Conversely, a weaker magnetic field, slower movement, or suboptimal coil design may yield lower energy output. By understanding and manipulating these variables, researchers and engineers can optimize electromagnetic induction-based energy harvesting systems. This knowledge enables the development of technologies that efficiently convert mechanical energy, such as wheel motion, into usable electrical energy. Harnessing electromagnetic induction holds significant potential for creating sustainable power solutions and advancing the field of energy harvesting.

1.2 Energy Harvesting Experimental

In electromagnetic energy harvesters, both coils and magnets play crucial roles as essential components. Specifically, in the context of wheel motion energy harvesting, the coil is strategically placed on the spokes of the hubcaps, while the magnet is positioned inside the coil. Figure 1 illustrates this configuration, where the coil is mounted on the spokes of the wheel's hubcap. Within the coil, the magnet is positioned in such a way that it can move linearly when the wheel rotates. This arrangement ensures a smooth and synchronized movement of the wheel during operation. As the wheel rotates, the linear motion of the magnet induces a changing magnetic field within the coil. According to Faraday's Law of electromagnetic induction, this changing magnetic field causes an electric current to flow within the coil. It is this electric current that represents the harvested energy, which can be utilized for various applications such as powering electronic devices or storing in batteries. By utilizing the motion of the wheel and the interaction between the magnet and the coil, electromagnetic energy harvesters offer a promising method for converting mechanical energy into electrical energy. This innovative approach holds potential for sustainable power generation and paves the way for advancements in energy harvesting technologies.

Figure 1. Schematic drawing illustrating placement of magnetic and coils in Spokes

To start the experiment for this model, we need to access three tests.

1- Dropping motion (free falling test):

2- magnetic with coil (Rotation motion).

Prior to discussing that better, let us talk about the basic equations for this motion, which are:

$$m.r^{\cdot\cdot} - \mathrm{m.r}\,\theta^{\cdot 2} + Ff + F_{\mathrm{m}} = -m.g.\cos\theta \quad (1)$$

$$m.r.\theta^{\cdot\cdot} + 2\,m.\mathrm{r}^{\cdot}.\theta^{\cdot} + \mathrm{N} = -m.g.\sin\theta \quad (2)$$

$$\mathrm{F_m} = \frac{\mathrm{I_r}}{v}\iiint\left(\frac{\mu_0\,\mathrm{I}\,\mathrm{R}^3}{2\,\sqrt[2]{(\mathrm{X}^2+\mathrm{R}^2)^3}}dv\right).dR\,.da\,.d\theta \quad (3)$$

Certainly! Let's explore the hypothesis related to the free-fall test in the energy-harvesting model. Based on equation (1) and ($\ddot{\theta}=0$, $\theta=0$) for the dropping motion, we can write:

$$m.\ddot{r}+F_m = -m.g$$

Figure 2. and 3 depict the components utilized in the experiment, including a PP (polypropylene) pipe, a disk magnet, and a copper coil. The experimental setup involves placing a coil bobbin at the center of the pipe, while the magnet is positioned within the pipe. To evaluate the energy harvesting capabilities of the system, various load resistors are connected to the terminals of the coil. By comparing the predicted values from the model with the measured voltages across the load resistors, the performance of the energy harvesting model can be assessed. During the experiment, it is important to note that if the magnet comes into contact with the pipe wall, the test needs to be restarted to ensure accurate results. This is likely done to ensure that the motion of the magnet within the coil is uninhibited and follows the desired rotational motion. The energy consumed by each load resistor can be calculated using the measured voltage across the resistor.

This calculation involves utilizing Ohm's Law, where the power (P) consumed by the load resistor is given by:

$$E = \int_0^t P_{load} \,.\, dt = \int_0^t \frac{V}{R} . dt \quad (4)$$

Here, V denotes the voltage across the resistor, and R represents the resistance of the load resistor.

By measuring the voltage and calculating the power consumed by different load resistors, the energy harvesting capabilities of the system can be quantified and compared to the predictions of the energy harvesting model. Overall, this experimental setup allows for the evaluation of the performance and efficiency of the energy harvesting model in converting mechanical motion into electrical energy.

Figure 2. Components of free fall experiment

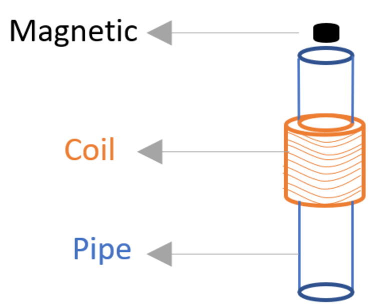

Figure 3. Illustration of a free fall experiment

The specification for each component of free fall:

Magnetic:

h (high)	19 mm
D (Diameter)	12.5 mm
m (mass)	18.5 kg
length of dropping the magnetic	160 mm

Coil:

H (High)	30.2 mm
R (resistance)	429 Ω
L (inductance)	0.98 H
R_1 (the inner radius of the loop)	13.1 mm
R_2 (the outer radius of the loop)	27.6 mm
a_1 (the beginning radial position of the coil)	58.4 mm
a_2 (the last radial position of the coil)	88.6 mm

Pipe:

Type	Poly Propylene grey RAL 7032 DN 150
Length	153 mm

When the magnetic move through the pipe there is a dipole moment magnetic which can calculate from the next equation:

$$M = V_m.\ B_r/\mu_0$$

B_r: Magnetic flux, it is equal about 1.19 (T).

V_m: Volume of the magnet, it is equal about (π h $D^2/4$).

μ_0: Permeability of free area, it is given as ($4\pi.10^{-7}$)

M: dipole moment magnetic.

There is a wide variation in the value of this parameter from one company to another, and it depends on the magnetic field strength. for our testing we can calculate the dipole moment value depending on the previous equation and the value it gives as 2.2 $A.m^2$

Results

By utilizing diagram 4, we can plot the voltage across a load resistor over time. In this particular analysis, we focus on the time interval between 0 and 4.5 seconds, with a load resistor of 500 Ω and a dipole moment of the magnetic equal to 2.2 A m^2. The plotted curves exhibit an "overshoot" phenomenon when the magnet traverses through the coil, causing the voltage to momentarily return to zero. When the direction of the pipe is reversed, the magnet moves in the opposite direction upon reaching the end of the tube. Consequently, the voltage does not exhibit a significant increase. As a result, this effect has minimal impact on the average energy harvested.

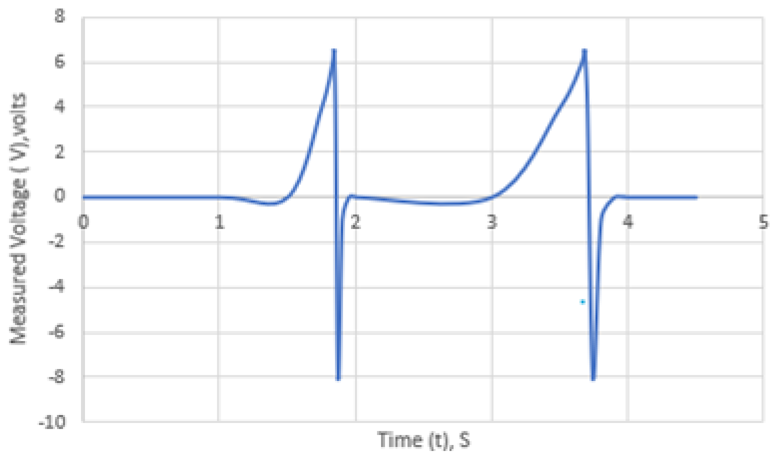

Figure 4. Relationship between measured voltage and time

The following Scheme 5 illustrates the results obtained by calculating the energy using equation (4) with various resistances:

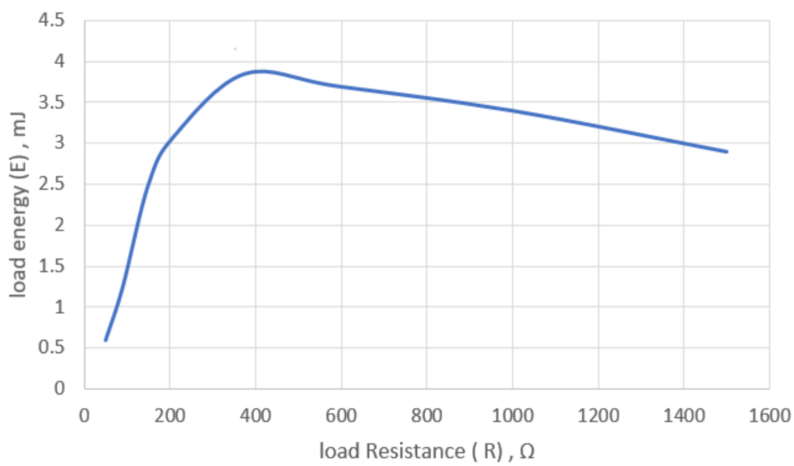

Figure 5. Relationship between measured energy and load resistance

In this analysis, we evaluated the energy harvested from the system by employing different resistances. Equation (4) was utilized to calculate the energy, taking into account the relevant parameters and variables. Considering the maximum energy value as 3.77 mJ and the coil's resistance 429 Ω as 3.74 mJ, the difference between maximum and coil values is 0.03. Thus, to estimate the maximum power output, it is preferred use a load resistance equal to the coil resistance.

<u>Magnetic with the Coil (Rotation motion)</u>

A similar rotation of the car wheel can be used in this experiment as a stand fan. Also depending on equations (1) & (2). Also, similar to the component of the first test we use also the disk magnetic, pipe P.P. and coil. we add here the device for the counter of rotation (Tachometer), and a counter sensor for touch magnetic at the last position of the pipe. The rotation experiment is shown in Figure 6.

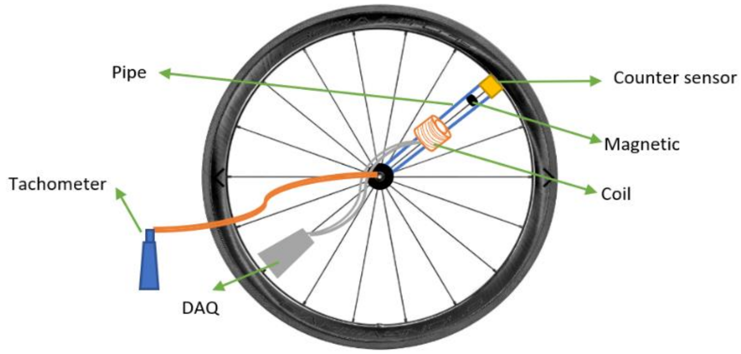

Figure 6. The second case of rotation experiments

The specification for each component of rotation experiment:

Magnetic:

h (high)	19 mm
D (Diameter)	12.5 mm
M (mass)	18.5 Kg

Coil:

H (High)	30.2 mm
R (resistance)	429 Ω
L (inductance)	0.98 H
R_1 (the inner radius of the loop)	13.1 mm
R_2 (the outer radius of the loop)	27.6 mm
a_1 (the beginning radial position of the coil)	77.8 mm
a_2 (the last radial position of the coil)	103.0 mm

Pipe:

Type	Poly Propylene grey RAL 7032 DN 150
Length	153 mm

In this example, a wireless DAQ device 9191 measures the voltage and transfers the values to a laptop as show in figure 7 also the Load resistance (R, load) 170 Ω.

Figure 7. Wireless Data Acquisition 9191

Results:

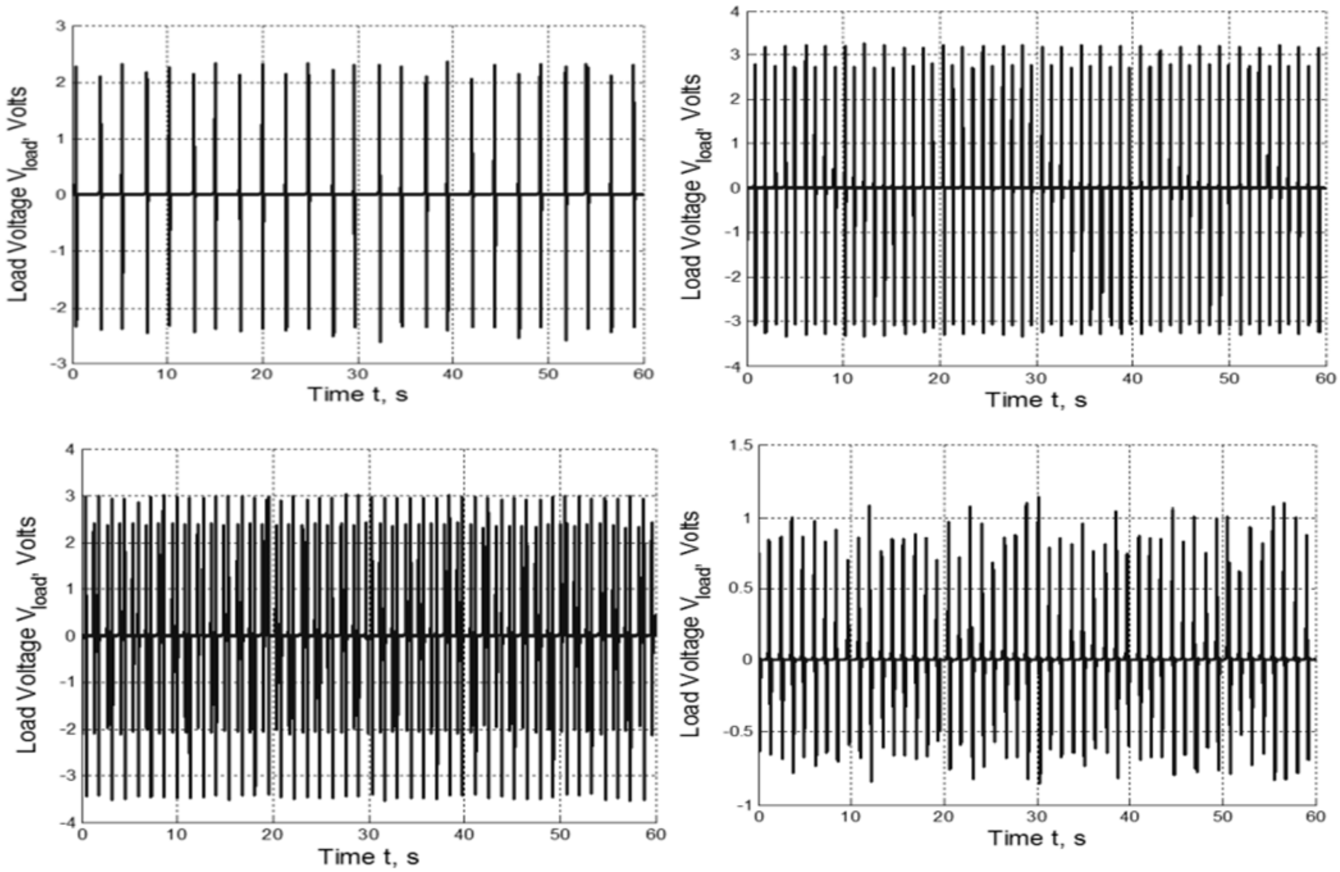

Figure 8. Relationship between the voltage and time (1) RPM=23, (2) RPM=27, (3) RPM=42, (4) RPM=49

These graphs show the calculated effort for 60 seconds, and the greater the number of rotations of the wheel, the more voltage curves there are, and in the end, due to friction, the peaks become irregular.so it is better to check the energy by friction and without friction. In figure 8. Refer about the load energy (mW) and number of rotation (RPM) without friction.

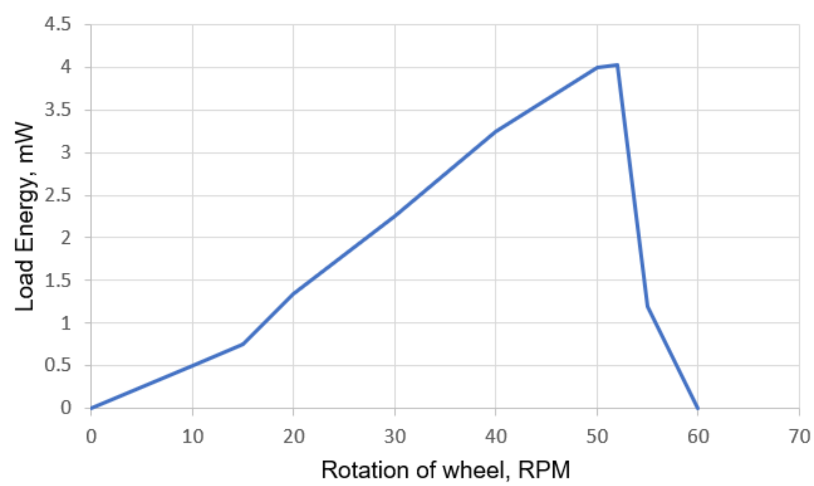

Figure 9. Relationship between the Energy and number of rotations without friction

But in figure 10. Show the load energy and number of rotations of the wheel with friction

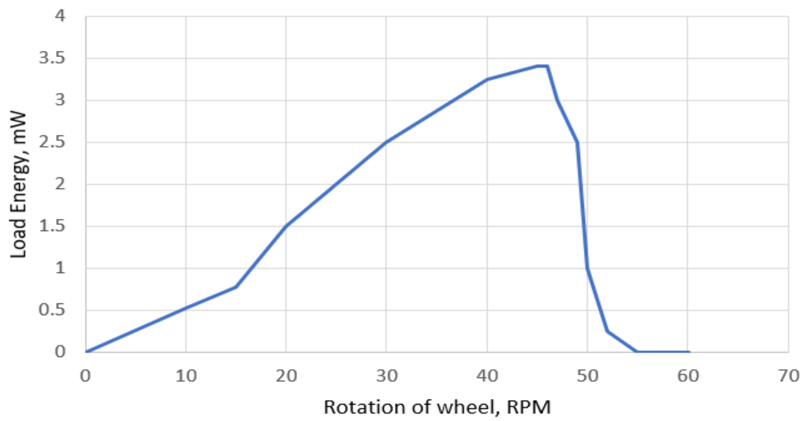

Figure 10. Relationship between the Energy and number of rotations with friction

When the rotation of the wheel increases, the average amount of energy increases. In addition, we observe that the energy level declines sharply after the peak. During this decrease in energy, the magnet undergoes a centrifugal force to overcome gravitational pulling. Consequently, the magnet will not fall completely to the bottom. As a result of the model without friction, the output of energy is about 4.02 mW at 53 RPM, but as a result of the model with friction, the output of energy is about 3.4 mW, and of course that is because we have the static friction coefficient when the magnetic starts sliding, and the kinetic friction coefficient on the magnet as it moves.

CONCLUSIONS

Based on the previous design, we discovered that the direction of the wheel is responsible for the movement of the magnet within the fixed coil, which generates energy. This harvester gave as 4.02 mw for 60 rpm for the rotation experiment and for free fall about 3.77 mJ. Maybe in the future, there will be development in this design that can suitable for more energy.

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