Magnetic Levitation

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Abstract

In the past ten years, magnets and the magnetic fields they create have been part of a major boost in modern technology. Maglev trains and Eddy braking are two examples of the many applications that use changing magnetic fields to create magnetic levitation or magnetic braking. Companies like Hendo have produced hoverboards using strong neodymium magnets, utilizing their strong magnetic fields. These magnets are configured in a Halbach array which creates an amplified field on one side of the array and a diminished field on the opposite side. When this array is positioned in a circular pattern and spun, the changing magnetic field produces a lift force that can carry as much as 192 kg. Although the construction and application of this array has already been completed, there is currently no theory relating all of the variables part of this hovering machine. Using empirical data, a relationship between all of these variables can be found and then derived from Faraday's law of induction.

1 Introduction

Manipulations of magnetic fields continue to be growing as a part of technological advancements and have the potential to create important civilian applications. Maglev trains are the most recent advancement that use eddy currents, caused by changing magnetic fields, to accelerate trains up to 375mph [1]. Further research on these changing magnetic fields can be done on a smaller scale. One application is a hoverboard. The Hendo hoverboard uses this idea to create a magnetic levitation device [2]. The device consists of four magnetic rotors connected to a pad in which a person or object can stand on. Hovering over a conductive surface, which is normally copper or aluminum, the device is essentially frictionless and can move with ease and little external force.

Inside of the rotors, the magnets are arranged in a Halbach array [2]. This is explained further in a different section. When the rotors are spun at high speeds, the changing magnetic field creates an eddy current in the conductive surface. The eddy current in turn creates an opposing magnetic field, with a net force that is perpendicular to the conducting surface [3]. Hendo's work with magnetic levitation inspired this independent study and our work is based on their patent. However, we wish to extend the information known about magnetic levitation by quantifying the relations between the levitation force, angular velocity, distance, power, and thickness of conducting surface. Note that all figures referenced can be viewed in the appendix.

2 Halbach Array

Halbach arrays are used all throughout science and aids greatly in the advancements of technology. They are used in free electron lasers and particle accelerators [4]. A Halbach array is also a key component when creating magnetic lift. A simple, linear Halbach array can be viewed in Figure 1. In this array, the north is indicated by an upward arrow. When magnets are aligned in this manner, there are two strengths of fields produced, a strong and

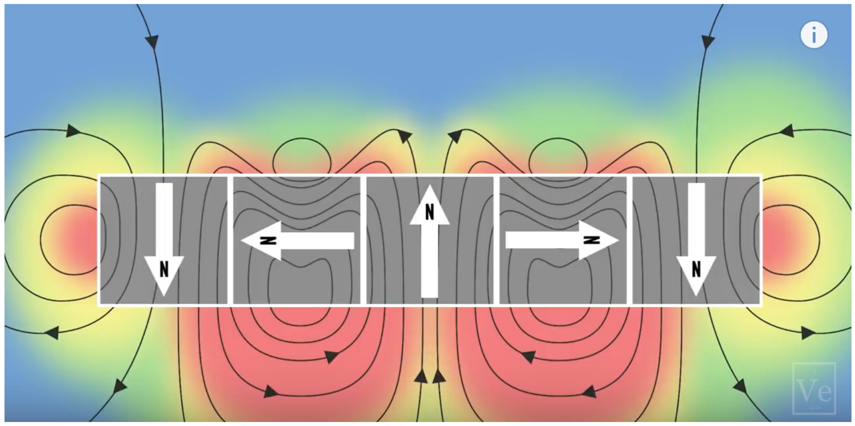

Figure 1: A liner Halbach array that shows the positioning of magnets and the strong and weak field produced by this array [3].

weak side [4]. The strong side is produced by the constructive interference of the magnetic fields while the weak side is a result of destructive interference. The weak side has a magnetic field that is more than half that of the strong side and can be given by the following equation [2],

$$F(x,y) = F_0 e^{ikx} e^{-ky}$$

where F_0 is the magnitude of the field at the surface of the array and k is the spatial frequency($\frac{2\pi}{\lambda}$). The pull force is determined by the strength of the overall magnetic field. Having a linear vision is important to reference when this array becomes circular. The circular configuration of this array allow for easier rotation, less air friction and an even stronger field. The circular array created can be seen in Figure 2. This is just a blueprint that was used as a reference to create our own rotor (Figure 3).

To show that the magnetic field is, in fact, stronger and that our array is correct, magnetic film was placed on top of the weak and strong side of the rotor. The darker spots indicate a stronger field while the lighter areas indicate a weaker field. These images can be seen in Figure 4 and Figure 5 respectively.

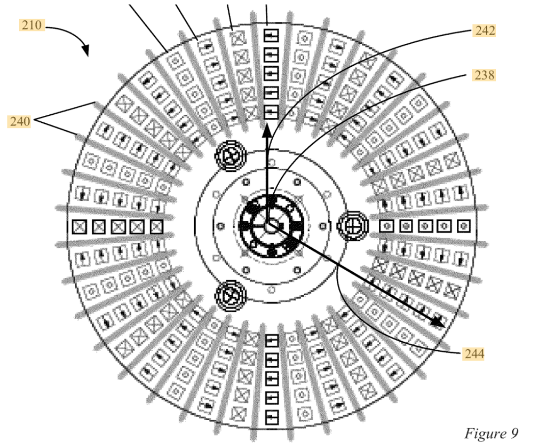

Figure 2: A circular Halbach array used as a reference when creating our own model [2].

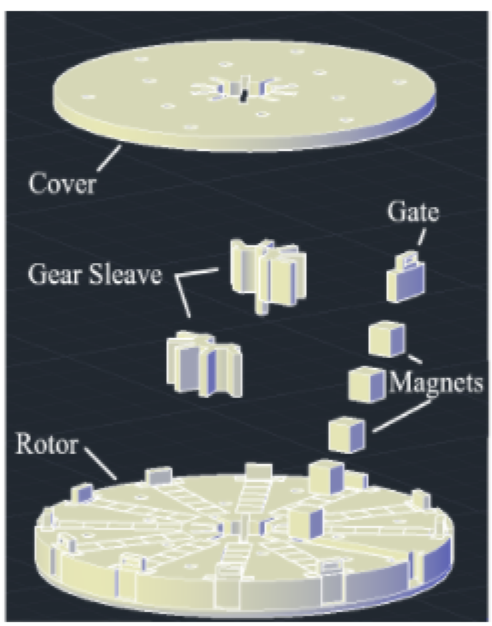

Figure 3: The rotor designed for testing using the Hendo model as a reference.

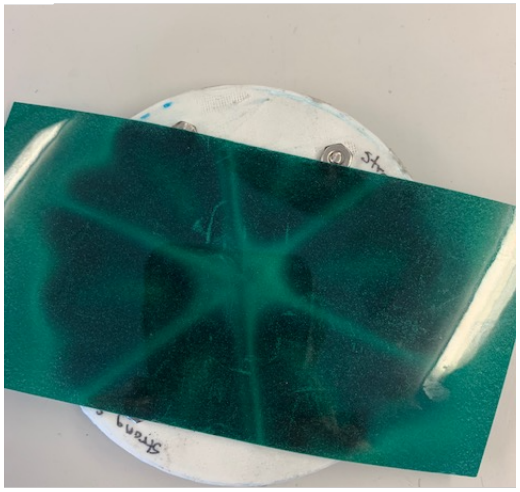

Figure 4: An image showing the strong magnetic field produced by the circular Halbach array. The darker areas indicate a strong magnetic field.

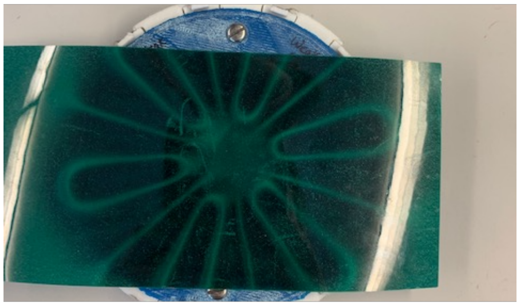

Figure 5: An image showing the weak magnetic field produced by the circular Halbach array. The lighter areas indicate a weak magnetic field.

3 Theory

Now that Halbach arrays are understood, it is important to understand what is happening to cause the magnetic lift. When a permanent magnet is moved near a conductive object, such as a metal object, eddy currents are established in the conductive object, which generate an opposing magnetic field. For example, when a permanent magnet is dropped through a copper pipe, an opposing magnetic field is generated which significantly slows the magnet as compared to a non-magnetic object dropped through the pipe. This effect is described by the Faraday Lenz's law (2).

$$\varepsilon = -\frac{\delta \Phi}{\delta t} \tag{1}$$

Where epsilon is the electromotive force (V), phi is the magnetic flux (T/m^2), and t is time.

As the law states, when the magnetic field through an area is changed over time there will be a resultant potential (voltage). It is this potential that creates the eddy currents in the conducting surface. Ampere's laws declares whenever a current is moving it will generate a magnetic field. This magnetic field made by the eddy currents is a mirror image of the original magnetic field, which causes opposition. However, when the fields are changing fast enough there will be enough vertical force to counteract gravity.

4 Construction

In order to better understand and analyze the mechanics of magnetic levitation we devised an apparatus to perform experiments with. Making four equal rotors, similar to Hendo, would be expensive, time wasting and ineffective. Therefore, one rotor was made so that testing could be analyzed more clearly. A picture of the experimental setup may be seen in the Figure 6. The source of our magnetic field is a specifically designed rotor which contains 60 .25in neodymium cube magnets (N52). Using a Gauss meter we found that the strong side of the rotor has a magnetic field of .18T on its surface. Throughout the semester the rotor

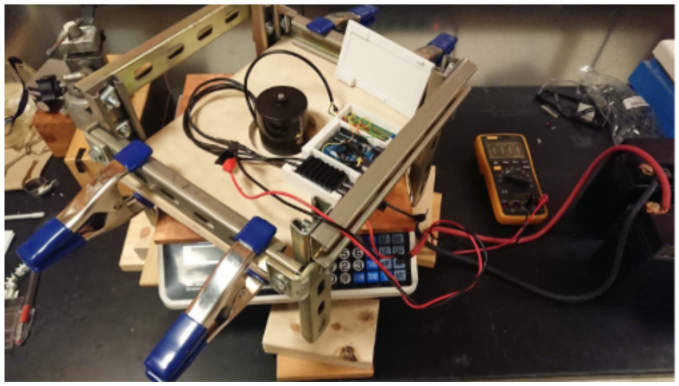

Figure 6: Experimental setup.

was redesigned and rebuilt multiple times to make it lighter, safer, and easier to manipulate. The final design is shown below in an image from AutoCAD showing each component that composes the rotor. The 3D printed PLA rotor consists of twelve rows that have five magnets in each row creating a circular Halbach. So that the magnets do not flip and stay in place, there is a cover which is blue. These two parts are screwed down together to ensure that the magnets inside of the rows do not move. The third part are the gates which close off these rows. These gates ensure that the magnets do not shoot out of their slots once the rotor is spinning. The gates are friction fitted, but a layer of a gorilla glue and epoxy mix is applied to the gates to solidify their placement.

Powered by 4 12V 20Ah batteries connected in series a 170kv brushless DC motor spins the 3D printed rotor. An Arduino Uno and a 60A electronic speed controller (ESC) are used to vary the speed at which the motor operates. In addition to speed control the Arduino also interprets hall sensor data to output revolutions per minute. Unfortunately, at this time the code used to interpret the hall sensor is not operating correctly.

While most of the semester was spent designing the rotor and troubleshooting ESC problems the rest was spent creating a rig that could hold the motor and rotor stable. The structure of the rig is constructed out of unistrut steel and plywood. The structure was designed to immobilize the rotor so that the copper plate may be adjusted up and down to test the relation between height and magnetic lift. The copper plate is on a scale with

5g divisions to measure the magnetic lift force, under the scale is a scissor jack allowing for easy manipulation of height. We chose a 3/8in thick 1sq. ft. copper plate as our conducting material due to its low resistance and high conductivity. While it is more expensive than aluminium it is also 63% more conductive leading to a greater opposing magnetic field [5].

5 Testing

After we designed the experimental setup, testing of magnetic levitation and its variables began. The goal of our testing is to keep some variables constant and change others, to create a well formulated empirical function. These variables include the thickness of the conducting device, angular velocity of the spinning rotor and distance between the rotor and conducting surface. These changing variables will be tested in regards to the force it produces and graphed individually to see its role in the overall magnetic levitation.

Although testing has not commenced yet, we are confident we have a strong plan for testing; with a solid foundation and proper materials to work with, it will make testing these changing variables smooth and eliminate some errors that previously had been taken into account. Once every variable is tested and we know for certain the relationships between these changing factors and the lift force produced, this will make creating a magnetic levitation device easier, more cost efficient, and give some direction to future students and engineers who may want to work with magnetic levitation.

6 Conclusion

While this semester's independent study of magnetic levitation did not produce the functions we had hoped for, we were able to build a solid foundation for future testing. Along the way we were able to learn invaluable skills and techniques that may help us with any other research we may pursue. After future testing has been completed and an empirical formula is found, a formula may be derived to explain the relationships between magnetic levitation and angular velocity, distance, power, and thickness of conducting surface. Through this project, we hope to gain greater funding for Physics Club and show our findings and data to other students of SUNY Oswego and the scientific community.

7 References

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2. Henderson, G. (2013). Magnetic levitation of a stationary or moving object. doi: https://patents.google.com/patent/US20140265690

3. Veritasium. (2017). Electromagnetic levitation quadcopter. doi: https://www.youtube.com/watch?v=pCON4zfMzjU

4. Masi, James. (2013). Overview of Halbach magnets and their applications. Electrical Manufacturing and Coil Winding Expo 2010-2013. 134-139.

5. Wire and Cable, Networking, Security and Utility Power Solutions. (n.d.). Retrieved from http://www.anixter.com/.

8 Appendix

Figure 7: Electronics that include an Arduino Uno, motor controller and circuit board

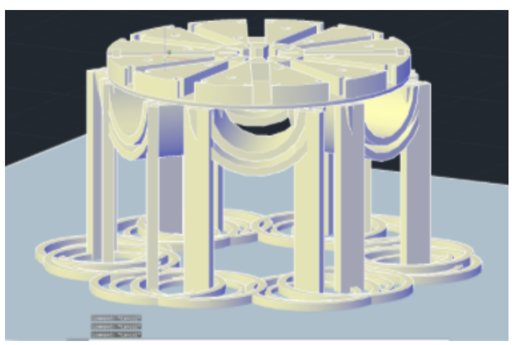

Figure 8: Representation of eddy currents induced by the applied magnetic field.