Computational Numerical Analysis of a Magnetic Flux Permanent Magnet with Different Shape for The Development of a Hybrid Generator

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ABSTRACT

A hybrid generator is one of the attempts to reduce carbon emissions in electricity generation, as it could replace the combustion system currently used in generator sets to generate electricity while increasing carbon emissions. In the hybrid generator system, Lenz's rule of electromagnetic induction is applied in reverse by using a relay to change the polarity of the solenoid coil's electric current. The permanent magnet in the solenoid coil generates mechanical energy (motion) and thereby moves the generator engine, since the permanent magnet is connected to the generator engine via the crankshaft. The objective of this study is to determine and compare the behaviour of N55, N52, N42, N42SH, and samarium-cobalt permanent magnets for the magnet system. The objective of this study is also to find a suitable permanent magnet for use in the magnet system to increase the power generation efficiency. A simple model is simulated to achieve the desired result, including magnetic flux density inside and around the magnets, magnetic field strength calculation, and applied force. The simulations and analysis are performed using ANSYS R19 software and finally all the data are recorded and compared to select the best magnet and develop a prototype. The permanent magnet inside the solenoid plays an important role in the hybrid generator and it is crucial to choose the suitable permanent magnet to increase the efficiency of power generation. From the data, Alliance N-55 permanent magnet has the highest

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magnetic force of 131.57 N for 1 mm because it has significantly higher magnetic flux density, magnetic flux intensity and magnetic force.

Keywords: *Hybrid Generator; Permanent Magnet; Magnetism*

Introduction

In today's world, fossil fuels are one of the primary sources of energy currently used, whether to generate electricity or for transportation. Even though renewable energy sources have been discovered for years, they are not as efficient or stable as fossil fuel sources [1].

Most renewable energy sources came from the environment such as solar energy. Solar energy is renewable energy that requires sunlight to generate electricity, and this technology can only be used during the day since the solar source is a photovoltaic cell panel, this system necessitates a large amount of space for the panel. Nowadays, the study of renewable energy focuses on magnets as the main source still in the preliminary, and difficult to find a focus journal on it as a reference.

A hybrid generator gets its inspiration from electromagnet energy to move the mechanical system in the generator. This system differed from existing generators in that the diesel or gasoline generator used a combustion system to move the mechanical system in the generator. This generator project defines how to produce electricity from green energy or renewable energy by using magnetic mechanisms as the sources to produce linear mechanical energy and rotate the brushless motor and generate electricity. Essentially, the concept was like a generator that generates electricity using oil and diesel. In the combustion chamber, the air is oxidized by the combustion generator, which uses a heat engine and fossil fuel as a source [2]. Internal combustion produces high pressure and high temperature, which generate force and moves mechanical energy.

The hybrid generator innovation is part of sustainable development to provide renewable energy to future generations. Furthermore, electromagnet energy was green energy that had no side effects or pollution to the environment or habitat [3]. With this generator innovation, it will be possible to electrify the entire world, especially in rural and island areas where electricity supply is difficult to obtain. In addition, the low input current to high output current generator innovation is one of the most stable energy outputs in renewable energy than other renewable energy. For the economic sector, it can reduce the cost of living for people who are affected by the rising price of fossil fuels. This generator's innovation has the probability to become one of the primary sources of electricity generation around the world.

Permanent magnet

Many engineering applications and devices have chosen magnetic material to replace some traditional engineering applications to achieve optimal performance and efficiency [4]. The use of permanent or temporary magnets can also be beneficial to the environment. Mechanisms that use magnetic elements, for example, can significantly reduce heat generation and thus increase machine efficiency. Magnets such as Neodymium type magnets are an excellent choice for producing efficient output due to their capabilities and low operating temperature, particularly in applications requiring electrical motors [5]. Since Neodymium is a type of permanent magnet containing rare earth material, its supply is limited over time. Nowadays, the most promising permanent magnet without the use of rare-earth materials with high magnetic energy and low cost is the Iron Nitride magnet. Based on their findings, they believe that the Iron Nitride Magnet permanent magnet will be a viable replacement for the Neodymium permanent magnet [6].

Faraday’s law

The law of electromagnetic induction was discovered by Michael Faraday. The discovery of electromagnetic induction led to the development of generators and transformers. Faraday experimented to demonstrate the ability of magnetic fields to induce currents. As Michael Faraday demonstrated, a changing magnetic field can induce an electromagnetic field in a circuit. The induction of a magnetic field can be demonstrated by conducting a closed-circuit wire loop with an ammeter (A) and a bar magnet placed above the wire loop's center axis. When the magnet is held stationary inside the loop, there is no current in the loop. Based on his observations, Faraday concluded that the induced current is related to the changing magnetic field [7].

$$\varepsilon = N\frac{\Delta\Phi \mathrm{B}}{\Delta t} \quad (1)$$

According to the equation, is the magnetic flux and B is the electromotive force (EMF), also known as the induced voltage. The number of coils can be increased to generate more flux changes, which will increase the EMF's overall strength. Consequently, where N is the number of coils turns.

Lenz’s Law

Lenz's law is an electromagnetism law that is primarily related to electromagnetic induction. The focus of Lenz's law is the direction of the current induced in a circuit by the effect of a magnetic field. According to Lenz's law, the current generated in the coil counteracts the flux change caused by the moving magnet [7]. The mechanical linkage produces linear movement in the solenoid by reversing the Lenz Law. The magnetism concept reverses the concept by manipulating the direction of the current to change the polarity of the electromagnetic field of the solenoid. By manipulating the current, the permanent magnet will produce a linear movement inside the solenoid since the electromagnetic field inside the solenoid is changing shown in Figure 1.

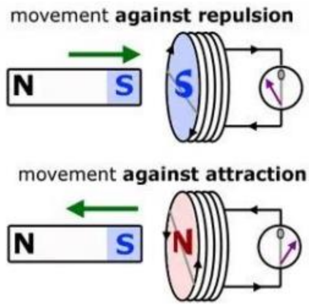


Figure 1: Lenz's law concept [7]

Electromagnetic induction and Lenz's law are both closely related to electromagnetism laws. Lenz's law focuses on the direction of the current that is induced into a circuit as a result of changes in the magnetic field. It is stated in Lenz's law that the flux change caused by the moving magnet is offset by the current produced in the coil [7].

$$\varepsilon = -N \frac{\Delta \Phi B}{\Delta t} \tag{2}$$

As a result, the equation has a negative sign. In opposition to the moving magnet, which applies a mechanical force, the magnetic field from the coil will act. A repulsive force can be felt when a magnet bar is introduced into a coil because the magnet and coil both have the same pole and magnets with similar magnetic poles repel one another. Another example is when a magnetic ball is dropped through an aluminium or copper pipe, this phenomenon is visible. The magnet moves noticeably more slowly through the pipe than if it were dropped into thin air.

Magnetic flux

Magnets of various forms are commonly utilized in a vast array of electromagnetic devices today. Transformer cores are the most prominent example of a device that utilizes magnetic flux. In order to induce EMF across secondary coils from the same core more effectively and with better flux distribution, it is necessary to assess the magnetic flux in the air gap between the core windings of the transformer [8].

According to the idea, magnetic flux is the motion of a magnetic field through a surface. Magnetic flux is the number of magnetic field lines that traverse a body [9]. A surface with a vector area is subjected to a magnetic flux represented by:

$$\Phi_B = BA \cos \theta \tag{3}$$

where:

ΦB = Magnetic Flux (Wb)
B = magnetic field magnitude (T)
A = surface area (m2)
θ = angle between magnetic field lines and normal to the surface area

Halbach array arrangement

Dr. K. Halbach of the Lawrence Berkeley National Laboratory in the United States proposed the Halbach array, which is a permanent magnet structure. The Halbach array can produce extremely high and consistent flux densities without the use of electricity or cooling. Figure 2 shows a strong magnetic field can be created on one side by arranging several permanent magnets in a linear form and magnetizing each magnet in a different direction according to a specific order of arrangement; however, a weaker magnetic field will also be created on the opposite side of the permanent magnet [10].

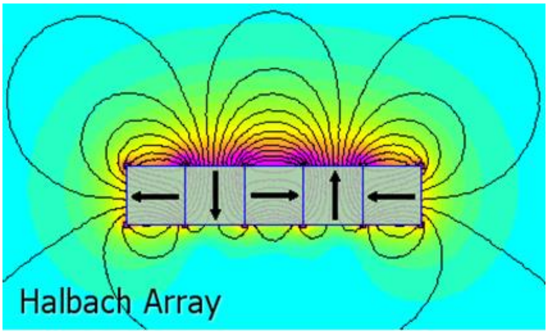


Figure 2: Halbach array arrangement [10]

Hybrid generator

The hybrid generator gets its inspiration from electromagnet energy to move the mechanical system in the generator. This system differed from existing generators in that the diesel or gasoline generator used a combustion system to move the mechanical system in the generator. This generator project defines how to produce electricity from green energy or renewable energy by using magnetic mechanisms as the sources to produce linear mechanical energy and rotate the brushless motor and generate electricity [11].

Essentially, the concept is like that of a generator that generates electricity using oil and diesel. In the combustion chamber, the air is oxidized by the combustion generator, which uses a heat engine and fossil fuel as a source. Internal combustion produces high pressure and high temperature, which generate force and moves mechanical energy. But for the concept of an electric generator, this device will innovate the internal combustion system to the electromagnet system energy to move the linear mechanical energy. For the prototype shown in Figure 3, the linear mechanical energy is produced by generating an electromagnet field at the solenoid to move the cylinder's permanent magnet inside the solenoid core [12]. By manipulating the current, the cylinder's permanent magnet will produce a linear movement inside the solenoid since the electromagnetic field of the solenoid is changing. The concept of the system was inspired by combining and reversing Lenz's Law with a permanent magnet.

The permanent magnet inside the solenoid plays the important role in the hybrid generator and it is crucial to decide the suitable permanent magnet so that it can increase its efficiency to generate electricity. For this project, the goal is to choose a suitable type of permanent magnet in terms of its grade, shape, and arrangement of the permanent magnets since it can affect the strength of the permanent magnet and its movement inside the solenoid.

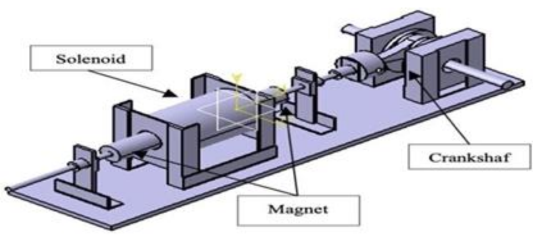


Figure 3: Prototype of hybrid generator

Methodology

The methodology for all the simulations and analysis is conducted by using Magnetostatic Analyse System in ANSYS Software R19 Version and all the data of the analysis are obtained from the Magnetostatic solver.

Data input

The data input section mainly focused on applying the magnetic properties of the materials that have been collected from the Alliance LLC website into the ANSYS software shown in Table 1. Alliance LLC is a nationally recognized supplier of magnetic materials for the automotive, industrial, defence, alternative energy, and communication industries in the United States and the company provides various data about the mechanical and magnetic properties of all the permanent magnets 2 types of magnetic properties of the permanent magnets that were required for the analysis which is the Magnetic Remanence (Br) and the Magnetic Coercive Force (Hc). Magnetic Remanence is the amount of ability of a material to acquire and keep its magnetic properties.

For the Magnetic Coercive Force, it is the amount of magnetic field required to demagnetize the material. So, the Magnetic Remanence will increase linearly with the Magnetic Coercive Force. The larger the Magnetic Remanence, the larger the Magnetic Coercive Force will be. Below were the Magnetic Remanence and the Magnetic Coercive Force for each of the 5 permanent magnets that were used in the analysis.

Table 1: Magnetic properties of permanent magnets

Permanent Magnets	Magnetic Remanence, B_r (T)	Magnetic Coercive Force, H_c (A/m)
Alliance S-28H Samarium Cobalt Magnetic Material	1.10	835558.50
Alliance N-42 Neodymium Iron Boron Magnetic Material	1.30	994712.50
Alliance N-42SH Neodymium Iron Boron Magnetic Material	1.30	1114078.00
Alliance N-52 Sintered Neodymium Iron Boron Magnetic Material	1.48	1114078.00
Alliance N-55 Sintered Neodymium Iron Boron Magnetic Material	1.52	1153866.50

Designing

There were 2 types of software that have been used in designing which are ANSYS SpaceClaim and ANSYS DesignModeler. Each of software has its advantages and disadvantages to design the geometry for the simulation. ANSYS SpaceClaim is design software that is friendly to the user while ANSYS DesignModeler is design software that gives freedom and flexibility to the user in designing certain geometry for the analysis. The design software that has been used is ANSYS SpaceClaim and the design consists of a cuboid shape permanent magnet (25 x 10 x 50 mm) and cylinder shape permanent magnet (249.99 x 2 x 50 mm) shown in Figure 4.

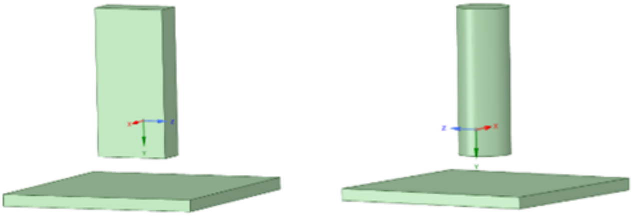


Figure 4: Cuboid and cylinder shape permanent magnet

For the solenoid, the dimension was 120 mm in length and with an inlet radius of 30 mm. The solenoid consists of 500 turns shown in Figure 5. The design must be in a hollow semi-cylinder to apply the current input and voltage input at the interior surface of the solenoid so that it can be analysed in magnetostatic analysis.

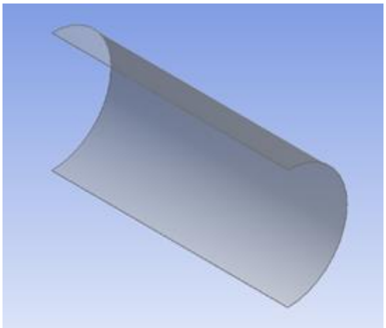


Figure 5: Solenoid design in semi-cylinder

Meshing

The meshing section is the one that will decide the accuracy of the results and it will depend on the sizing of the meshing because every intersection point between the mesh elements is the node. The smaller the sizing of the meshing, the more the number of nodes and the more the accuracy of the result. However, it will take a long time to get the results, and it will depend on the capability of certain ANSYS software. The mesh sizing for this project was 5 mm which is the default amount of the meshing for this software shown in Figure 6 and the detailed meshing for this simulation is shown in Figure 7.

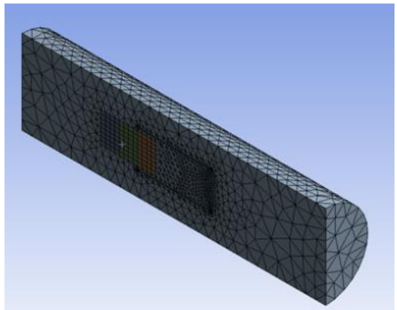
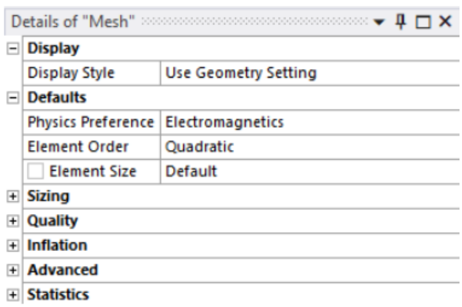


Figure 6: Meshing sample



Details of "Mesh"	
Display	
Display Style	Use Geometry Setting
Defaults	
Physics Preference	Electromagnetics
Element Order	Quadratic
Element Size	Default
Sizing	
Quality	
Inflation	
Advanced	
Statistics	

Figure 7: Meshing parameter

Analysis

The magnetostatic analysis can give the results of the magnitude of flux density, the magnitude of flux intensity, and the magnetic force of the permanent magnet. However, the magnetostatic analysis is dependent on the enclosure of the analysis illustrated in Figures 8 and 9. The enclosure represents the surrounding since the type of surrounding and temperature can affect the magnetic field such as air and vacuum condition. For the project, the environment temperature is 22 ˚C type the enclosure was air and applied on the cuboid shape.

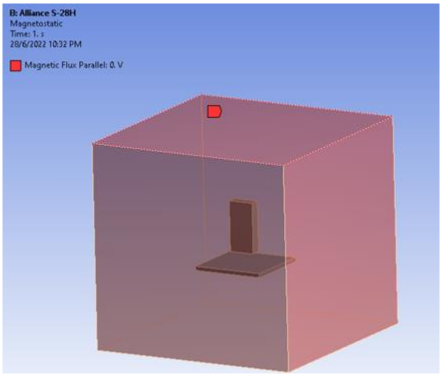


Figure 8: Magnetostatic analysis for cuboid shape

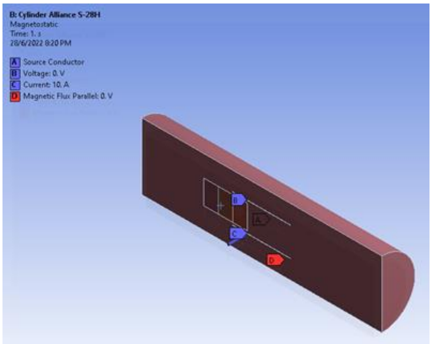


Figure 9: Magnetostatic analysis for cylinder shape

Results and Discussion

For the analysis, the cuboid shape permanent magnet had been placed 10 mm above the plate and the magnetostatic analysis analysed the behaviour of the magnetic field and the magnetic force from that location.

Due to the cuboid shape of the permanent magnet, the greatest magnetic flux density is located between 20 mm and 30 mm from the permanent magnet, as shown in Figure 10. Figure 11 shows that the largest magnetic flux density was located at the ends of the cuboid-shaped permanent magnets, and the ability to magnetise other ferromagnetic materials is greater at the ends than in the middle. Figure 12 shows that as the distance between the permanent magnets and the cast iron plate increased, the force summation of the permanent magnets to the cast iron plate decreased.

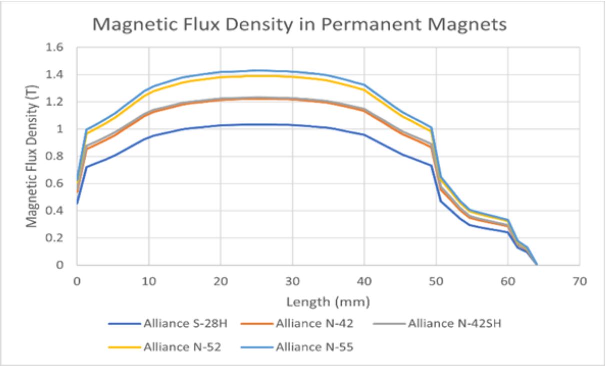


Figure 10: Magnetic flux density across the body

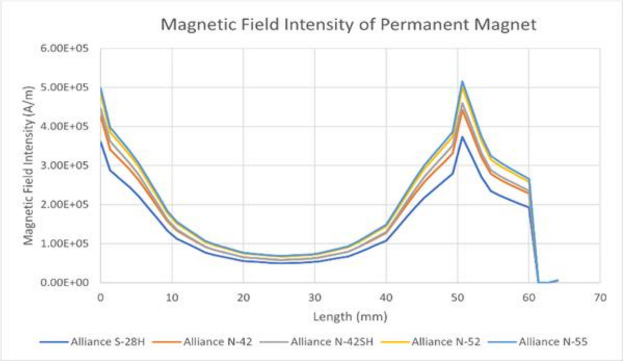


Figure 11: Magnetic flux intensity across the body

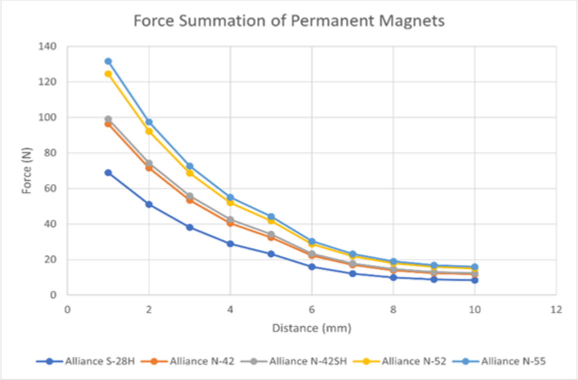


Figure 12: Force summation of permanent magnets

Figure 13 shows the results of comparing two different shapes of Alliance N-55 permanent magnets, a cube shape and a cylinder shape. The plots show the magnetic flux density, the magnetic flux strength, and the sum of the forces between the two shapes. With 2 mm and 1 mm between the permanent magnet and the cast iron plate, the sum of forces for the cube-shaped Alliance N-55 is slightly higher than for the cylindrical-shaped Alliance N-55, 25.71%. For the same height, contact area and volume, the cuboid-shaped permanent magnet is slightly stronger than the cylindrical permanent magnet, as shown in Table 2.

Table 2: Force summation between cylinder shape and cuboid shape permanent magnet

Distance (mm)	Force Summation (N)	
	Cylinder Shape Permanent Magnet	Cuboid Shape Permanent Magnet
1	104.66	131.57
2	89.36	97.45
3	70.49	72.64
4	56.89	55.10
5	43.94	44.23
6	31.92	30.33
7	24.58	23.16
8	20.42	19.02
9	17.49	16.905
10	15.31	15.96

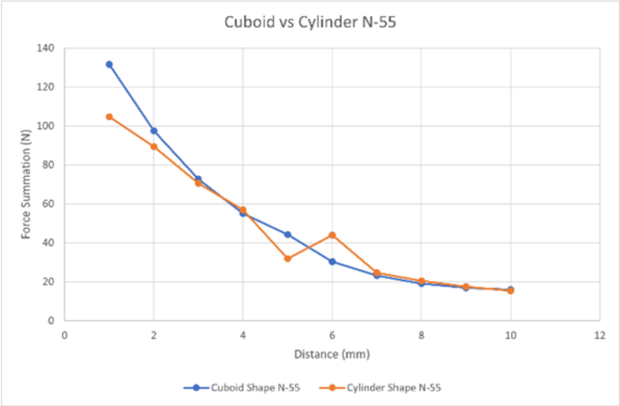


Figure 13: Force summation of cuboid and cylinder shape N-55

The direction of the magnetic field for the 2-semicylindrical permanent magnet was outward from the aluminium half-cylinder (middle half-cylinder), hence the north pole is at the end of both cylinder shapes. For the cuboid shape, each end of the design represented the strongest side of the magnetic field data. Figures 14 and 15 show the magnetic field behaviour for the two shapes within the magnetic core. Since the purpose of the analysis was to study the behaviour and magnetic strength of the permanent magnet of the magnetic core, only one type of current flow, 1.0 amps, was used. The magnetic coil generates an electromagnetic field with the north pole on the right side and the south pole on the left side, with a magnetic flux density of 0.045 T and a magnetic flux strength of 36151 A/m at the centre of the core.

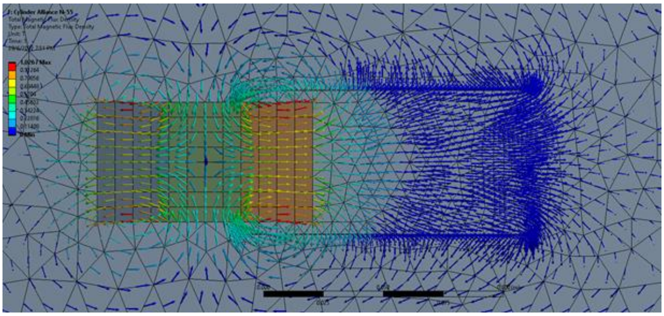


Figure 14: Design 1 inside solenoid core

The magnetic field in the core of the Design 1 solenoid was in one direction only, indicating that the north pole (right side) of Design 1 was facing the north pole of the solenoid. Therefore, they repelled each other, and since the north pole (left side) of Design 1 was facing the south pole of the solenoid, they attracted each other and caused a linear motion to the left.

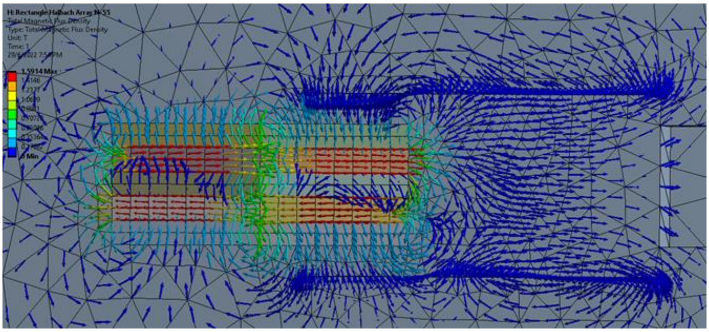


Figure 15: Design 2 inside solenoid core

Thus, the presence of the south pole on the strong side (both ends) of Design 2 slightly attracts the permanent magnet toward the north pole of the solenoid, causing the opposite movement of the permanent magnet for the hybrid generator system. This result is tally that already discuss in Energy Management through Electromagnetic Conversion the resulting output power depends crucially on the design, the covered area among the magnet and coils, the lineal or angular velocity induced, the relative permeability of the implemented materials, and the time-varying magnetic field generated, as well as the magnetic flux density and magnetic field strength of the magnets [4].

Conclusion

Based on the results, the Alliance N-55 permanent magnet had the strongest magnetic force because the permanent magnet had the highest magnetic flux density, the highest magnetic flux intensity, and the highest magnetic force among the other permanent magnets. However, the availability of the N-55 permanent magnet is limited because the N-55 grade is still new to the market. In addition, the difference in the shape of the permanent magnet also affects the magnetic force of the permanent magnet, and the result shows that the cuboid permanent magnet performs better than the cylindrical permanent magnet. So, the most suitable permanent magnet for this hybrid generator is the cuboid N-55 permanent magnet.

The results show that the force sum for the cuboid Alliance N-55 is 25.71% higher than that of the cylindrical Alliance N-55 at 2 mm and 1 mm between the permanent magnet and the cast iron plate. With comparable height, contact area and volume, it can be concluded that the cuboid permanent magnet is slightly stronger than the cylindrical permanent magnet. This study also can conclude that electromagnetic conversion provides a modern background between renewable energy systems, exergy analysis and electromagnetic engineering concepts to ensure long life, instant power generation, efficiency, performance and optimization of energy.

Contributions of Authors

The authors confirm the equal contribution in each part of this work. All authors reviewed and approved the final version of this work.

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Conflict of Interests

All authors declare that they have no conflicts of interest.

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