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Characteristics and Performance of an AFPM Generator Design Using Coin-Shaped NdFeB Magnets

[1]Sudirman Syam, [2]Nursalim, [3]Wellem F. Galla, [*4]Sri Kurniati
*[1,2,3,*4]Department of Electrical Engineering, Faculty of Science and Technology, Nusa Cendana University, Kupang-NTT, Indonesia*

Abstract
This experimental study examines the characteristics and performance of an Axial Flux Permanent Magnet (AFPM) generator using a 3 x 25mm neodymium-iron-boron (NdFeB) coin-shaped magnet. Coin magnets have high flux and are easily available in the market. In the installation, the magnets are mounted in layers on the rotor disc made of acrylic as a substitute for iron material. The goal is to reduce magnetic reluctance and eddy current losses, which impact increasing the magnetic flux and generator output voltage. The method used is experimental testing by measuring the generator output voltage without load and load. The results showed that the performance of the AFPM generator with four layers of coin magnets could increase the output voltage of the generator. In addition, testing the output voltage with variations of the stator coil is also carried out. In testing the generator with four layers of coin magnets, the output voltages are 4.88 Volts (43 turns), 6.1 Volts (86 turns), and 16.76 Volts (172 turns).

Keywords:*Axial generator, Magnetic flux, NdFeB, Output voltage*

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I. INTRODUCTION

Micro-hydro Power Plant (MPP) and Wind Power Plant (WPP) utilize water flow energy and wind energy as an energy source to drive a generator. In particular, WPP generally uses a low rotation speed generator, below 1000 rpm [1]. The use of a low-speed generator is because, although wind energy is always present, the speed is not always high all the time. In Indonesia, the average wind speed ranges from 3.5 to 7 meters per second [2]. Because the intensity of energy sources is not constant, a solution is needed to continue to produce electrical energy. The goal is that electrical energy needs can be met even at low rotation speeds. Due to its low rotating characteristics, a permanent magnet axial generator (AFPM) is very suitable for WPP applications [3]. Axial generators use permanent magnets with the rotor and stator positioned perpendicular to their axes. There are two main components in an axial generator, namely the rotor and the stator. The rotor is equipped with a permanent magnet as a moving part, while the stator contains a coil as a stationary part. In the AFPM generator, electrical energy is obtained from the magnetic flux due to the rotation of the rotor and changes the magnetic field in the stator coil.

AFPM generator designs are being developed and are very well integrated with wind turbines such as the Savonius. AFPM type generators are increasingly becoming the dominant use with competitive prices, especially in using high energy permanent magnets. This machine offers many unique features or models and is more efficient because the field excitation losses are eliminated, reducing rotor losses significantly [4, 5]. Thus, motor efficiency can be increased, and higher power output can be achieved [6].In addition, AFPM has a thin thickness and uses small magnets resulting in small generator dimensions/size [7]. AFPM can be designed taking into account the higher ratio of power generated in coreless materials. In addition, AFPM is planar, which makes it easy to adjust the air gap. The noise and vibration levels are less compared to conventional machines (RFPM). Likewise, the air gap flux direction can be changed, and many topologies have been made. The existence of several advantages of AFPM machines compared to conventional machines (RFPM) make this APFM machine used in various applications such as single-sided, double-sided, torus models, and multi-disk designs (Chalmers et al., 1997).

Generally, the generators available in the market are conventional high-speed generators between 1500 to 3000 Rpm. This type of generator requires electrical energy to produce a magnetic field [5]. On the other hand, AFPM generators have the advantage of being simple in construction. The use of a generator is more efficient than a machine that uses windings in its rotor, and it does not require electrical energy to generate a magnetic field. In addition, AFPM generators are easy to make according to the desired power capacity, voltage, and rotational speed by changing a few parameters. Such as the magnetic field, the number of coils, the magnet's size, and the diameter of the wire used [6]. The use of magnets made from Neodymium Ferrite Boron (NdFeB) also influenced the development of the AFPM generator design. The permanent magnet has a strong (remanent) magnetism and a large magnetic flux [7]. In this study, a new design of the AFPM generator has been developed using coin magnets. The aim is to determine the performance and design characteristics of the AFPM generator using coin magnets. Besides having a large magnetic flux and being easy to obtain in the market, the advantages of this coin magnet.

II. MATERIALS AND METHODS

2.1 Structure and Design Concept

In this study, a coin-shaped NdFeB permanent magnet with a size of 25 x 3 mm was used as a magnetic field source in the rotor (Figure 1).

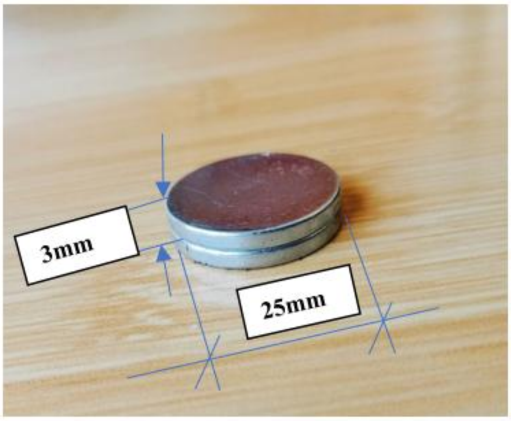
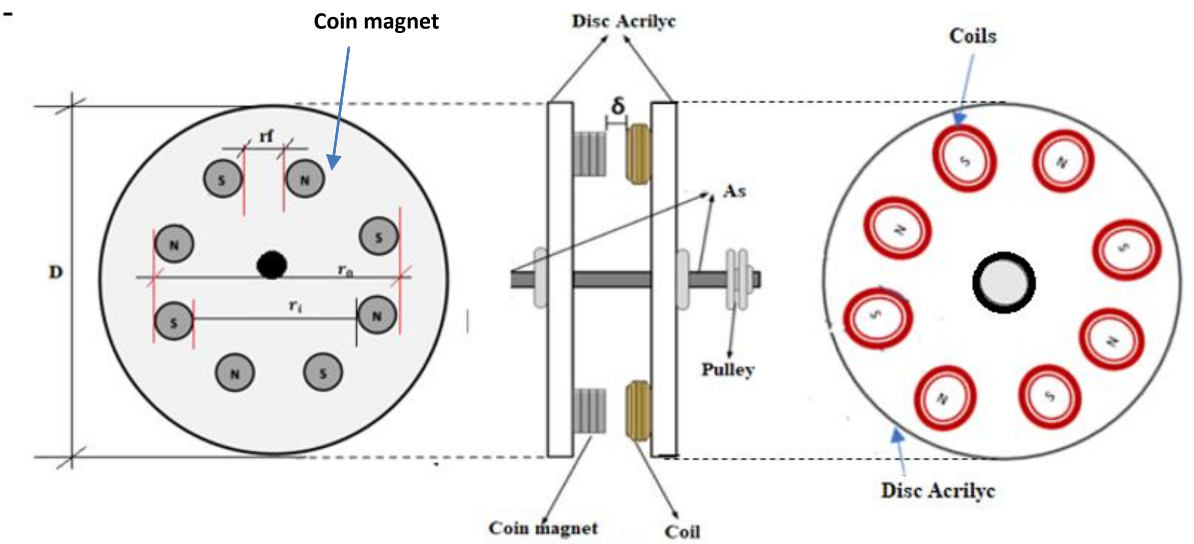


Fig. 1:Coin magnet

We propose an axial model and a simple shape for the generator configuration, as shown in Figure 2. Each pair of rotor magnet poles is attached with several coin magnets arranged in layers 1 to 4. A Teslameter is used to measure the magnetism of each layer before being attached to successive rotor plates. 98.95 mT (1 layer), 171.88 mT (2 layers), 248.29 mT (3 layers), and 282.38 mT (4 layers) respectively. The air gap between the rotor and the stator is 1 mm. Figure 3 shows the configuration of the AFPM generator that was tested experimentally. The geometric parameters of the prototype are in Table 1.



(a) (b) (c)

Fig. 2: Axial Generator Design. (a) Rotors; (b) Rotor and Stator Design; (c) Stator

Table 1: Specifications of the AFPM GeneratorDevice are Shown in Figure 3.

No.	Parameter	Quantity	Symbol
1.	Disc diameter, (mm)	245	D
2.	Outer radius, magnet, (mm)	170	Ro
3.	Inner radius, magnet, (mm)	120	Ri
4.	Distance between poles, (mm)	30	Rf
5.	Air gap distance, (mm)	1	φ
6.	Magnet diameter, (mm)	25	
7.	Magnet thickness, (mm)	3	
8.	Average Flux Density: 1 layer; 2 layers; 3 layers; 4 layers	0.098; 0.171; 0.248; 0.282	Br
9.	Number of coils, (turned)	43; 86; 172	
10.	Number of phases	1	
11.	Number of poles	8	

III. RESULT AND DISCUSSION

3.1 No-load Generator Performance Measurement

Figure 3 shows a generator test using a DC Shunt motor drive. In the figure, the two pulleys are connected to a DC motor and an AFPM generator via a transmission belt (n1=n2). The test system can measure generator performance characteristics ranging from speeds of 100-1000 RPM. The output voltage measurement is carried out by varying the magnetic layer under zero and loaded conditions. In the same way, tests for three different stator windings are also carried out—measured data such as load current, output voltage, and speed. In the no-load test for a generator for the stator, 43 windings, 86 windings, and 172 windings are shown in Figures 4, 5, and 6, respectively.

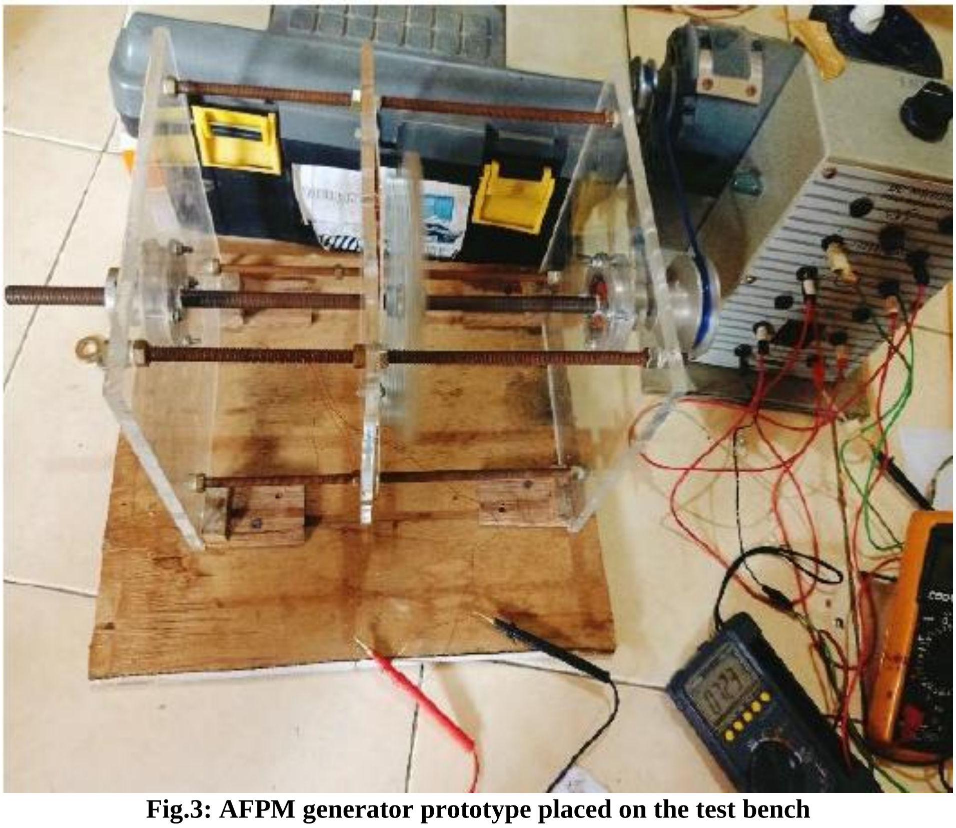


Fig.3: AFPM generator prototype placed on the test bench

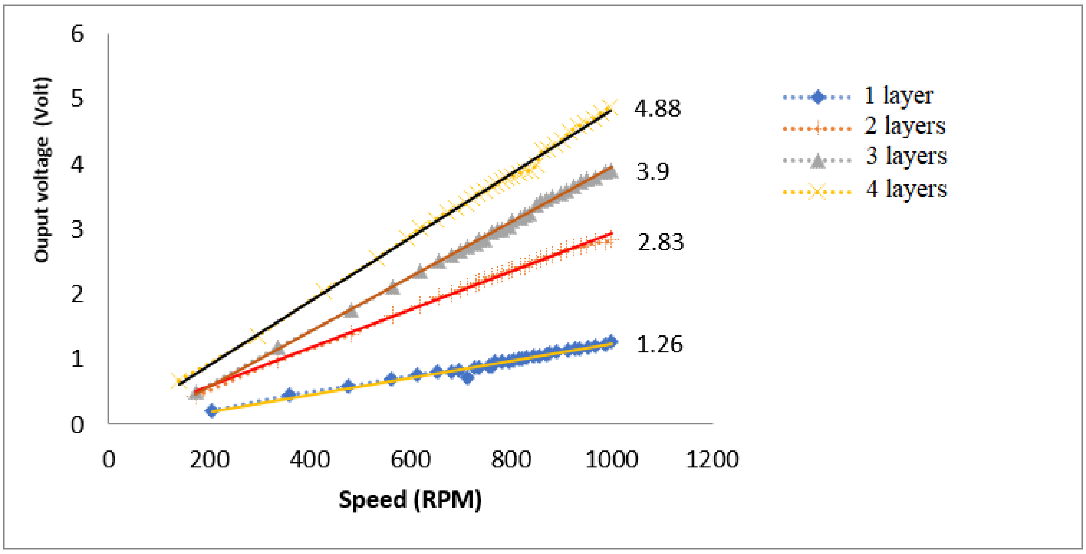


Fig. 4: Testing on the stator 43 windings

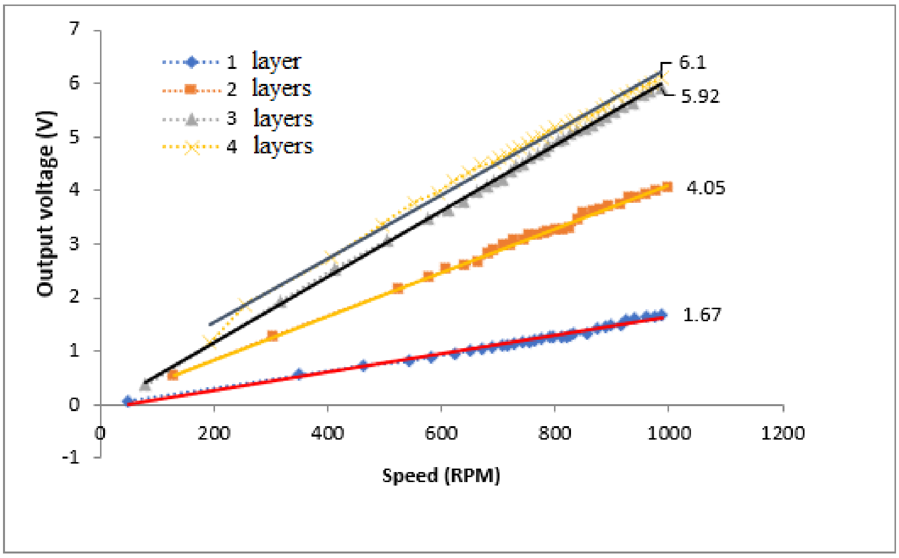


Fig. 5: Testing on the stator 86windings

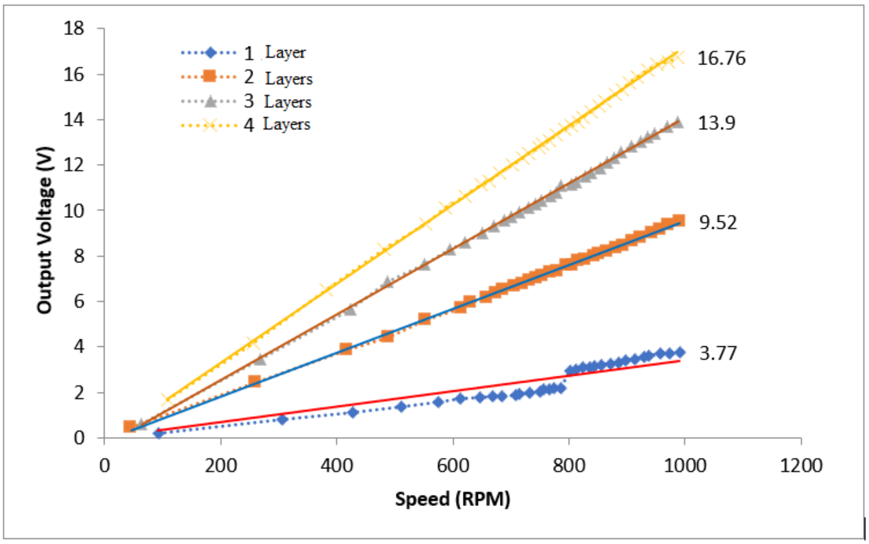


Fig. 6: Testing on the stator 172windings

Based on the figure, it can be seen that each layer of the magnet shows an increase in the generator output voltage. Likewise, the rotational speed of the generator is directly proportional to the output voltage. The higher the rotation of the generator, the greater the output voltage of the generator. The results of the measurement of the highest output voltage at 1000 rpm for each different number of stator turns are:

- 1.26 Volts (43 turns), 1.67 (86 turns), and 3.77 (172 turns) for 1 layer magnet
- 2.83 Volts (43 turns), 4.05 Volts (86 turns), and 9.52 Volts (172 turns) for two layers of magnets
- 3.90 Volts (43 turns), 5.92 Volts (86 turns), and 13.9 Volts (172 turns) for three layers of magnets
- 4.88 Volts (43 turns), 6.1 Volts (86 turns), and 16.76 Volts (172 turns) for four layers of magnets

3.2 Loaded Generator performance measurement

The test is carried out by using a 5 watts DC lamp. Because the generator output voltage is still AC, a diode bridge is installed to produce a DC output voltage. In this study, the generator output voltage test was carried out only on a rotor with four layers of magnets. Figure 7 shows a load test on a 43-winding stator, an 86-winding stator, and a 172-winding stator, respectively.

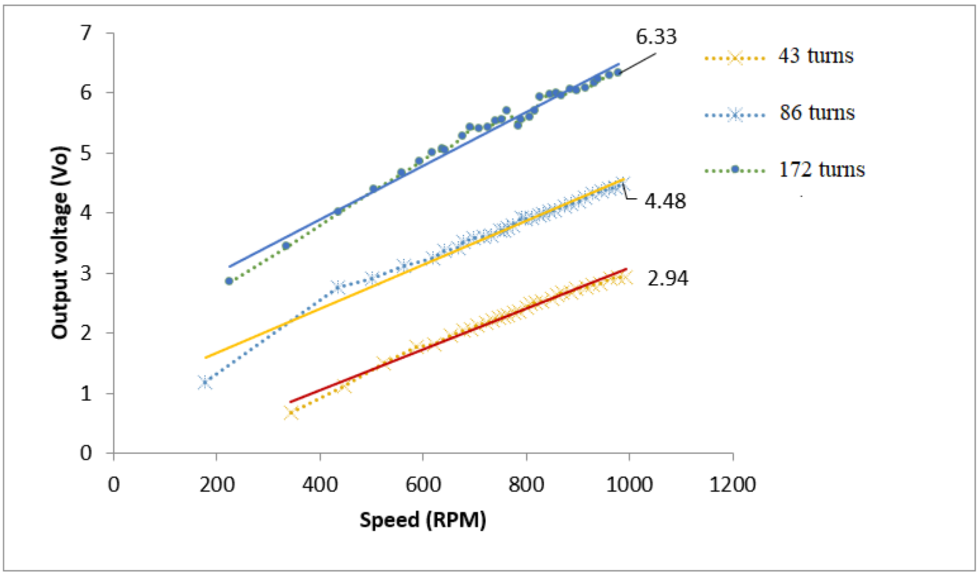


Figure 7. Comparison of loaded generator tests with varied stator windings

Based on the figure, it can be seen that the output voltage shows that the influence of the load on the three variations of the stator winding has decreased. As previously explained, a voltage of 4.88 Volts was obtained in the no-load test and a decrease of 2.94 Volts. In testing the 86-wound stator with an output voltage of 6.1 volts, the voltage decreased to 4.48 volts. Similarly, the 172-wound stator experienced a voltage drop of 6.33 Volts from 16.76 at no-load measurements. That also applies to other generators when given a load. The decrease in output voltage occurs because the generator is loaded. After all, a decrease in generator rotation accompanies it. When there is an increase in excessive load, the generator will stop rotating.

3.3 Discussion

The AFPM generator topology has been described in detail in [8]. Figure 2b is an AFPM generator consisting of one rotor disk (2a) paired with a coin magnet layer and one stator disk (2c) with several 8-pole coils. The stator windings and magnetic layer are sandwiched between two acrylic discs and mounted separately with a 1 mm air gap. The use of acrylic material aims to eliminate the effect of eddy currents that occur on iron materials. Then the installation of magnets in layers is intended to increase the magnetic flux. According to the paper [9], the magnetic circuit is arranged in parallel when the layers are layered together. Compared to a series circuit, if the magnets are arranged in parallel, the magnetic reluctance decreases, and the magnetic flux increases.

All these components are assembled manually after the stator windings, magnets, and rotor cores are constructed. The parameters of all generators were measured experimentally. When the rotor rotates, the magnetic field in the rotor will induce a coil in the stator, and at the ends of the coil wire will produce an electric voltage. The greater the number of layers, the greater the voltage generated. By referring to the theory of magnetism, the working principle of the AFPM generator is related to the interaction of several magnetic layers on the rotor with the stator winding so that there is an electromagnetic force that can generate a voltage on the generator. In addition, the use of coin magnets in the manufacture of the rotor can increase the output voltage compared to rectangular magnets. At the same size and dimensions, the highest voltage was obtained at 16.76 volts in this study, compared to the previous study [10] using a rectangular magnet of only 7.5 volts.

IV. CONCLUSION

In this study, we developed and tested an AFPM generator using coin magnets with the most important conclusions obtained summarized as follows:

- The higher the rotor magnetic flux value, the greater the output voltage generated. The highest flux value was obtained on coin magnets arranged in 4 layers, namely 282.36 mT.
- The larger the stator winding, the greater the generator output voltage. The number of turns 172 obtained the highest output voltage of 16.76 Volts with a rotation of 1000 rpm.

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