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A New Design of Magnetic Gear Axial using a Rectangular NdFeB Magnetic Layer

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Abstract. Characteristics of magnetic-gear axial using 4 rectangular NdFeB magnetic layers mounted on acrylic disks have been studied experimentally. The goal is to reduce the use of NdFeB magnets to be more economical compared to other magnetic gear designs. The magnetic gear axial topology made was different from the magnetic gear that had been made by the previous researchers. The method used is to conduct experiments by taking comparative data between motors that are directly coupled to the generator with that using magnetic transmission gear. The results obtained show that using 4 layers of the rectangular magnet with a magnet of 258 mT can increase the magnetic torque of the gear. Comparison of torque obtained at 200 Ohm load for direct coupling is 0.19 (N-m), while for magnetic transmission gear is 0.18 (N-m).

Keyword: Magnetic transmission, direct drive, DC motor

1. Introduction

In energy conversion, the DC generator voltage must be greater than the load voltage (V_L), therefore, to achieve nominal voltage; the generator must be rotated in the nominal rotation. When the generator rotation does not reach the nominal rotation, the generator output voltage will be smaller than the load voltage ($V_G \leq V_{G_{nom}}$). This condition results in no electricity flow from the generator to the load so that energy conversion cannot be extracted. Technically, the generator rotation can be increased through transmission gear between the shaft and rotor generator. Some energy transfer techniques have been used to increase rotation such as using a pulley, gearboxes [12], belts, transmission V. However, this transmission system has disadvantages such as mechanical losses, maintenance costs, expensive equipment, and noise. Researchers on mechanical systems, especially



those related to mechanical gears, have attempted to improve the efficiency of using gears used to transfer rotations. Bobak (2010) has summarized the efficiency of several types of gear such as a helical type ($\approx 96\%$), worm type ($\approx 79\%$), and Bevel spiral type ($\approx 92\%$). After that, Naunheimer (2011) provided information based on the results of a survey conducted on the efficiency of several types of gearboxes in full load conditions: manual gearboxes (92 - 97%), automatic gearboxes (90 - 95%), mechanical CVT (87 - 93 %), hydrostatic CVT (80 - 86%). However, the problem of lubrication, cooling, noise reliability and vibration for mechanical gear is still a major problem.

Based on the condition of mechanical gears, the use of magnetic field transmission is one promising alternative. In this case, magnetic teeth have been applied as one of the technologies that can replace mechanical teeth. Naturally, the principle of magnetic teeth is the same as a mechanical tool topology. Magnetic tooth displacement can replace iron teeth from mechanical teeth using magnetic north-pole (N) and south-pole (S). There are several advantages to magnetic gear including, eliminating maintenance and increasing reliability, no overload protection, reducing noise, high efficiency and eliminating contact / friction on the shaft ([14], [8], [4], [5]). In addition, slip and break away from the system when the overload compared with conventional gear when stopping or braking which could damage the machines [11].

Nowadays, various types of new magnetic gears have been proposed by previous researchers. [7] proposed a surface-permanent magnet type (SPM-type), using harmonic magnetic flux, [13] and [2] proposed a type of cycloid magnetic gear. Furthermore, [14] proposed axial type magnetic gear, and [8] proposed a type of magnetic gear with variable speeds. However, all of these designs have a very complex arrangement and use a lot of NdFeB magnets. NdFeB magnet type has high performance compared to other magnets. The use of NdFeB on axial type magnetic gear has been reported by [3] and [16]. However, there are a number of shortcomings that need to be considered in the use of permanent magnet types including, the strength of magnetic materials, breakability, and expensive costs compared to ferrite magnets. In addition, there are inherent problems about sufferings from a shortage of supply. In this paper, the acrylic material has been proposed in the construction of magnetic gear to reduce the use of NdFeB magnets. This acrylic material has several advantages, for example, has a strong, not hot, inexpensive structure so that it can reduce the use of magnetic materials.

2. Material and Method

2.1 Rectangular NdFeb magnet

Rectangular magnets with a size of 10mm \times 20mm \times 1mm were chosen for fabricating magnetic gears. For this configuration, we want to study the performance of gear when using a disc made of acrylic to reduce magnetic materials. In this study, a magnetic layer of NdFeB type of 10mm \times 20mm \times 1mm will be used as shown in Figure 1.



Figure 1. Rectangular NdFeB Magnet

2.2 The design concept

Figure 2 shows a configuration of a magnetic gear uses disc made of acrylic. Each pair of magnetic poles installed a number of magnetic layers were made of rectangular magnets with a thickness of 1 mm. Air gap distance between the disc was adjusted to 0.5 mm. A distance of 0.5 mm between two magnets gear is the most ideal for transferring high torque rotation [6], [19]. The geometrical parameters of the prototype are those of Table

1.

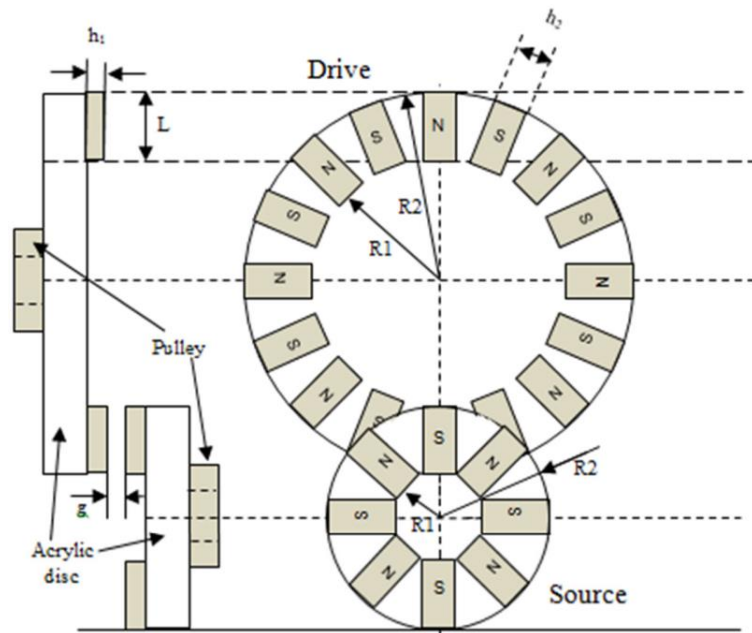


Figure 2. Geometric parameters of the proposed magnetic gear set

Table 1. Specifications of a magnetic gear set shown in Figure 2

Symbol	Quantity	Value
R_{1d}	Inner radius, drive magnets (mm)	40
R_{2d}	Outer radius of the acrylic discs, drive magnets (mm)	60
R_{1s}	Inner radius, source magnets (mm)	10
R_{2s}	Outer radius, source magnets (mm)	30
G	Length of air gap (mm)	0.5
h_1	Magnets thickness (mm)	1
h_2	Magnets height (mm)	10
L	Magnet length (mm)	20
N_d	Number of pole pairs (source magnets)	8
N_s	Number of pole pairs (drive magnets)	4
Br	Remanence of the permanent magnets (mT)	0.57
-	Direction of magnetization	axial

2.3 Experiment set up

Performance magnetic gear with DC drive motor and DC generator are tested with the following specifications:

- $V_{\text{supply}} > 30 \text{ Vdc}$
- Speed: 2750 rpm
- Torque: 10 kg.m
- Weight: 1.5 kg
- Current: 0.75A
- Power: 25 watts

The experimental set-up consisted of one multi-pole (main) driven by the shaft of an electric motor, while the other (slave) was mounted on a DC generator operating by a varied load. The motor was connected to a variable DC voltage power supply. Figure 3 are shown two types performance test is conducted by direct-drive and magnetic gear transmission. Measurements of torque and power were taken at load condition with speed, load, and the magnetic layer variation.

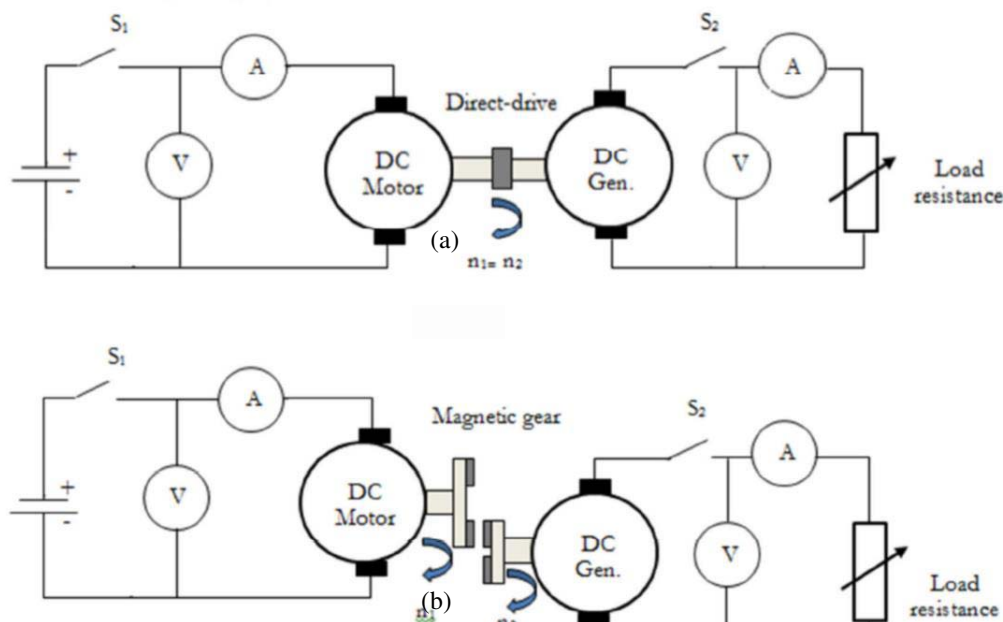
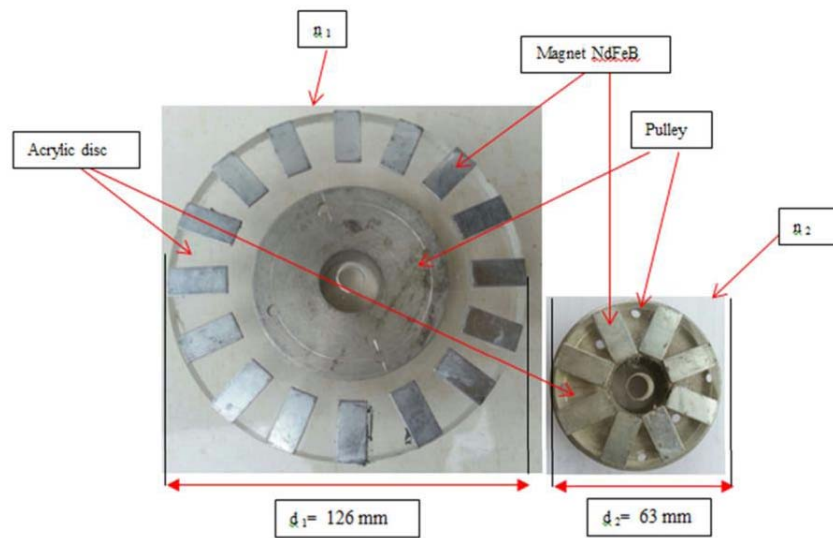


Figure 3. Sketch of dynamic test bench; (a) Testing with direct-drive, (b) Testing with magnetic gear

3. Result

3.1 The design of the magnetic axial gear proposed

Figure 4 shows the magnetic gear configuration using a rectangular NdFeB magnetic layer. Each magnetic tooth is installed using 4 layers of the magnetic rod with a thickness of 1 mm. The air gap is set at a distance of 0.5 mm. According to [6], a distance of 0.5 mm between 2 magnets is the most ideal distance for obtaining high magnetic torque. Figure 5 shows the test apparatus of the magnetic gear ($n_1 < n_2$).



(a)



(b)

Figure 4. Configuration of a magnetic gear axial using a rectangular NdFeB magnetic layer:
(a) Sectional front; (b) Rear sectional



Figure 5. Prototype of magnetic gear axial mounted on test bench ($d = 0.5 \text{ mm}$)

3.2 Measurement Results

Firstly, the test is carried out on the direct coupling system between the motor and the generator as shown in Figure 3a. After that, the data rotation, current and input, and output voltages are measured by the load varying 100-400 Ohm as configuration Figure 5b. Finally, the measurement data relationship between generator output voltage and rotation, it can be seen in Figure 6.

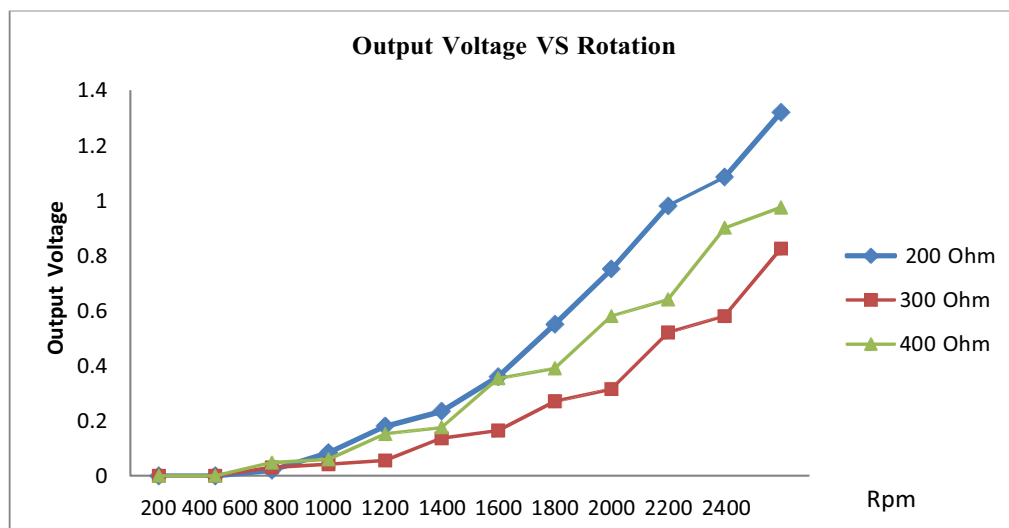


Figure 6. Relationship between output voltage and rotation

Based on Figure 6, it can be seen that there is an influence of the generator voltage drop on the given load. The greater the load given to the generator, the output voltage of the generator will decrease. This explains that the torque from the output of the generator depends on the given rotation. Therefore, when the generator output voltage decreases due to the addition of the load, the rotation must be increased until it reaches the desired voltage. Furthermore, Figure 7 shows the changes in torque to the addition of layers to each magnetic tooth. The addition of 4 rectangular Nd FeB magnetic layers with 258 mT can increase torque from magnetic gear. In this case, when conducting direct coupling testing between the motor and generator with 200 load has a torque of 0.19 (N-m), while the use of magnetic gear for 4 magnetic layers is 0.18 (N-m). That is, adjusting 4 magnetic layers on each magnetic gear gear is equivalent when the motor and generator are coupled directly at a 200 ohm load.

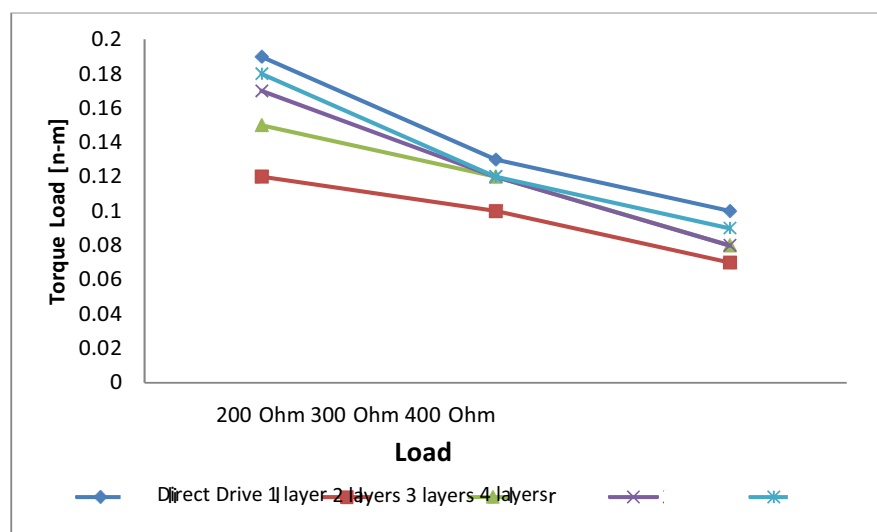


Figure 7. Comparison of torque between direct drive VS magnetic gear

4. Discussion

Magnetic gear fabrication using rectangular NdFeB magnets is an alternative to reduce the use of magnetic NdFeB. Therefore, this new design of magnetic gear axial has several advantages including, low cost, simple, it does not require the form of a special permanent magnet, and is easy to install. In addition, the use of acrylic as a frame in the manufacture of magnetic gear can reduce heat resistance, and improve the structure of the magnetic gear. Previously, the use of other materials such as plastic bonded was reported [1]. The results provide solutions to reduce the use of magnetic materials. The same method has also been carried out and reported in this paper such as by operating motors and generators in varying load conditions. As can be seen in Fig. 6 and 7 it has provided the characteristics and performance of the magnetic gear made from the arrangement of rectangular NdFeB magnetic layers. The design of the magnetic gear is very different from the previous design [9], [17], and [18]. In addition, another advantage of this design is not influenced by eddy current saturation because the frame is not made of iron.

5. Conclusion

1. The addition of 4 magnetic rectangular NdFeB layers of 258 mT has the same torque/approach to the motor and generator in direct coupling at a load of 200 ohms.
2. The use of rectangular NdFeB magnets in the manufacture of magnetic gear axial becomes more economical because it can reduce the use of NDFeB magnets.
3. The use of acrylic materials in the manufacture of magnetic gear can increase the strength of the magnetic gear.

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