''ELECTROMAGNETIC ANALYSIS OF MAGNETIC GEAR TRANSMISSION"

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A report submitted
in partial fulfillment of the requirements for the degree of
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DECLARATION

I declare that this thesis entitled "„"ELECTROMAGNETIC ANALYSIS OF MAGNETIC GEAR TRANSMISSION" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :

Name :

Date :

APPROVAL

I hereby declare that I have checked this report entitled "ELECTROMAGNETIC ANALYSIS OF MAGNETIC GEAR TRANSMISSION" and in my opinion, this thesis it complies the partial fulfillment for awarding the award of the degree of Bachelor of Electrical Engineering with Honours

Signature : .....

Supervisor Name : .....

Date : .....

DEDICATIONS

To my beloved mother and father

ACKNOWLEDGEMENTS

Alhamdulillah and all praise are to Allah, who promises his faithful servants victory. I would like to express my gratitude to Almighty Allah to enabling me to complete this report on "Electromagnetic Analysis of Magnetic Gear Transmission".

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ABSTRACT

Magnetic gears is widely used in many applications either in transportation, industrial machines, and power transmission. There are three types of magnetic gear which is coaxial magnetic gears (CMGs), linear magnetic gears (LMGs), and axial magnetic gears (AMGs). However, only a few literatures reported about magnetic gear especially to produce higher torque. The project main purpose is to model a new magnetic gear topology using FEM that could produce torque more than 1 Nm and analyse the torque and speed with a different parameter of permanent magnet, yoke, air gap and number of poles. The modelling of the magnetic gear starts using Solidwork and exported to using Maxwell ANSYS. This software simulates the magnetic gear includes electromagnet element such as flux density and magnetic field. The results show that magnetic gear has a high-speed ratio and generate a high torque at low speed. For the 2nd, the effects of the design model of magnetic gear and change the parameters of inner, outer magnet, diameter of yoke on the performance of torques are discussed. An air-gap thickness and other parameters will affect the maximum torques. As conclusion, this reasearch provides overview and guidelines of designing a new magnetic gear.

ABSTRAK

Gear magnet digunakan secara meluas dalam banyak aplikasi sama ada dalam pengangkutan, mesin perindustrian, dan penghantaran kuasa. Terdapat tiga jenis gear magnetik iaitu gear magnet sepaksi (CMGs), gear magnet linier (LMGs), dan gear magnet paksi (AMGs). Walau bagaimanapun, hanya beberapa literatur yang dilaporkan mengenai peralatan magnetik terutamanya untuk menghasilkan tork yang lebih tinggi. Tujuan utama projek adalah untuk model topologi gear magnetik baru menggunakan FEM yang boleh menghasilkan tork lebih dari 1 Nm dan menganalisa tork dan kelajuan dengan parameter yang berbeza magnet tetap, kuk, jurang udara dan bilangan kutub. Pemodelan gear magnetik mula menggunakan Solidwork dan dieksport menggunakan Maxwell ANSYS. Perisian ini menyerupai gear magnetik termasuk unsur elektromagnet seperti kepadatan fluks dan medan magnet. Keputusan menunjukkan bahawa gear magnet mempunyai nisbah berkelajuan tinggi dan menghasilkan tork yang tinggi pada kelajuan rendah. Untuk ke-2, kesan model reka bentuk gear magnet dan menukar parameter magnet dalaman, luar, diameter kuk pada prestasi tork dibincangkan. Ketebalan udara dan parameter lain akan mempengaruhi tork maksimum. Sebagai kesimpulan, kajian semula ini memberikan gambaran dan garis panduan untuk mereka bentuk gear magnet baru.

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LIST OF SYMBOLS AND ABBREVIATIONS

r_1	-	Inner rotor, r_1
r_2	-	Outer rotor, r_2
m_r	-	Rectangular Permanent magnet, m_r
y	-	Yoke
a_g	-	Air gap

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CHAPTER 1

INTRODUCTION

Many applications in power transmission and industrial machines used mechanical gears. Contact friction, noise, and heat are the examples inherent problem although their usefulness is important. One of the solutions for these mechanical problems is a development of magnetic gear [1].

In the early 1930s, the Magnetic gear‟s technology was proposed [2]. But in that period because of the lack of understanding in magnetic gear, they did not give more attention to obtain the great development. From 1970s, researches paid extra attention to a new technology which is the development of magnetic gear‟s technology. Since between moving parts there is no mechanical contact, lubrication is not compulsory and overload protection, electromagnetic gears are active in research as a new magnetic mechanical device. It can reduce the wear and tear that are commonly seen in mechanical gear systems because the magnetic gears work smoothly without any sound and it will not get heated as long as it works by using such kind of gearing systems [3]. Magnetic gear can be used in place of mechanical gear to reduce undesired vibrations and for applications that require high torque. Many application requires power input with a high torque and low-speed revolution.

Magnetic gear consists of two rotors which are each rotor has a different number of magnetic pole pairs and separated by a small air gap. Magnetic fields produced by inner and outer rotors are modulated by the ferromagnetic steel poles and create space harmonics in the air gaps [4]. The magnetic field on the inner and outer rotor interact with the modulated magnetic fields via the steel poles to transmit the torque. There are three types of magnetic gears based on their operations which is Linear Magnetic Gears (LMG), Coaxial Magnetic Gears (CMG), and Axial Magnetic Gears (AMG). The magnetic flux is typically generated radially inward and outward

with reference to the shaft axis for LMG and CMG. However, magnetic flux lines are created parallel to the rotor axis for AMG. But for this project only cover for CMG.

1.1 Project Motivation

Permanent magnets are used in magnetic gear to transfer torque between an input and output shaft without mechanical interaction which means that magnetic gears do not grieve from wear and losses associated with meshing teeth. The mechanism of power loss in mechanical gears is very different from those in magnetic gears. Magnetic gears can achieve efficiency at full load with much higher than a mechanical gear. Lubrication is not required since there is no mechanical contact between the moving parts. Magnetic gears protect against overloads by harmlessly slipping if an overload torque is exceeded while mechanical gears may be damaged under overload conditions. Magnetic gears are predicted to be low-noise devices because of a smooth torque transfer characteristics and absence of tooth contact. All these advantages motivated the author to study more on magnetic gear especially torque and speed characteristics for this project.

1.2 Problem Statement

In recent years, there have been considering many research and development activities on magnetic gear technologies. However, it is still not clear if this technology is ready for potential industrial applications because of the lack of knowledge of magnetic gear. For high performance, magnetic gear needs to be in high torque which will produce high torque density. Many researches have focused on improving the torque of magnetic gear by designing a new model of magnetic gear. So, in this project, a few modelling of magnetic gear is proposed.

The most studied topology of magnetic gears has been proposed by Martin and was the subject of different behaviour studies proposed by Atallah. One of the similar characteristics proposed by both of them is the shape of the permanent magnet which is used arc permanent magnet. The cost of arc permanent magnet is too high.

In summary, in this project a few modelling of magnetic gear is proposed by using rectangular a permanent magnet which has lower cost compare to arc magnet.

1.3 Project Objectives

This project aims:

i) To propose a model of new magnetic gear topology that has sets permanent magnet using Finite Element Method that could produce torque inner and outer rotor permanent magnet ratio 1:4.

ii) To analyse the torque characteristics with a different parameter such as air gap, number of poles, yoke and inner, outer permanent magnet.

iii) To select the best model that could produce torque inner and outer rotor permanent magnet ratio 1:4.

1.4 Project Scopes

The scope of the project includes understanding and analyzing the performance of torque and speed. Then, the magnetic gear is analyzed in order to get the best performance of the torque. First, a study has been conducted in searching any others previous magnetic gear in the journal or articles. Then, the magnetic gear will be developed based on theory and possible design method.

The design starts from magnetic analysis using Solidworks and simulated by using Finite Element Method (FEM). The FEM software known as ANSYS Maxwell is founded in 1970 which can determine the availability of magnetic characteristics such as flux flow, magnetic flux, and torque distribution.

The performance of the magnetic gear is need to analyze in order to get specifications which is torque. Based on the specification, the magnetic gear is designed by using Solidwork software and transferred to Ansys Maxwell software to simulate the design in order to get the desired torque. Next, based on simulation the best designed model of magnetic gear can be determined. Lastly, the best designed of magnetic gear will be model to further analysis. After that, by comparing the result of simulation a conclusion being made. This project does not cover eddy current loss, core loss, driver and no field test.

1.5 Thesis Outline

This report consists of 5 chapters. The first chapter of this report covers the research background, problem statements and objective of this project. The scope and report outline also included in this chapter.

The second chapter covers the literature review. All the theory that used to do analyse part is included in this chapter. The overview and operation of permanent magnet is also cover in this chapter. Besides, the description of the magnetic gear is cover in this chapter. The comparison between models of magnetic gear also cover in this chapter. The related research of magnetic gear is also cover in this chapter.

The next chapter is the methodology which explains in detail the procedures and steps for this research and project. Design and simulation software that are used to complete this project are also explain in this chapter.

The fourth chapter will be discussing about the result that obtain from the simulation. The final specification of the magnetic gear also discussed in this chapter. Lastly, the fifth chapter will be the conclusion for the project. The recommendation to improvise the design of the motor is also discussed in this chapter.

CHAPTER 2

LITERATURE REVIEW

Researches have shown interest and development a new technology incorporating permanent magnets with the achievement of technology. This idea is applied in magnetic gear to accomplish a concept of low-speed high torque operation [5]. Magnetic gear nowadays become popular because of contact-free operation, less maintenance, high reliability, requires no lubrication, and offer inherent overload. Because of these advantages, magnetic gear gets the better of the limitations of mechanical gearing system such as vibrations, noise, and friction due to contact. The magnetic field can be produced by using a permanent magnet which helps in the transfer of energy without contact. The process of transmitting power is silent and smooth differently with mechanical gearing system. Magnetic gears can be used to replace of mechanical gears to reduce unwanted vibrations and for the application that needs torque coupling between separated members [6].

2.1 The Construction of Magnetic Gear

Magnetic gear consists of two rotors, each with a different number of magnetic pole pairs separated by a small air gap.

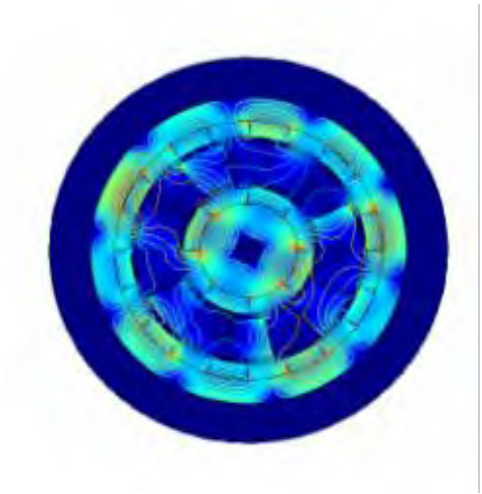

Figure 2.1: Modelling Of Magnetic Gear

In this configuration, the model consists of 4 pole pairs on the inner rotor, 11 pole pairs on the outer rotor, and 15 pole pairs in the middle (steel pole). The magnetic field with a dominant 4th harmonic produced by the 4 pole pairs on the inner rotor. To transfer torque, this field is modulated by 15 steel pole pairs to generate a field with a dominant 11th harmonic field that is produced by the outer rotor. This creates the torque as the field harmonic component from the outer rotor matches with the harmonic component created by the modulated inner rotor field [7].

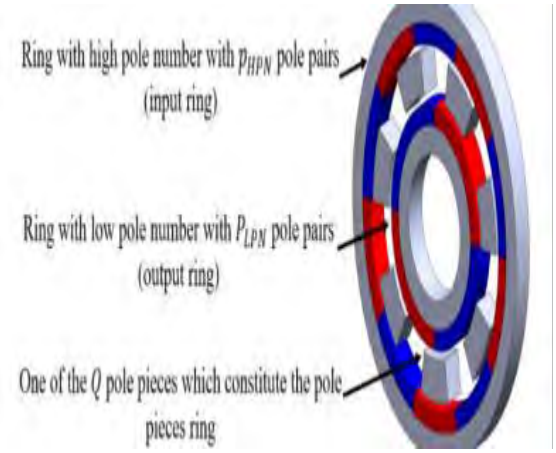

Figure 2.2: Magnetic Gear Arrangement

In [8], the general principle of the different magnetic gear with modulating ring arrangement can describe base on Figure 2.2. All the arrangement of magnetic gear with modulating ring are composed of three rings which is the ferromagnetic yoke with a ring with low pole number of pole pairs of permanent magnet, the ferromagnetic yoke and a ring with high pole number of pole pairs of permanent magnet and low pole number with a ring with ferromagnetic yoke pole pieces to improve readability.

2.2 Principle Operation of Magnetic Gear

As the power transmission device, the magnet was suggested for the first time by Armstrong C. G. in 1901 in his patent [9]. The gear consisted of two gears, which is one with electromagnets as the gear teeth and the other with steel pieces. According to their relative position to the secondary gear teeth, the electromagnets on the primary gear were switched on and off as shown in Figure 2.3.

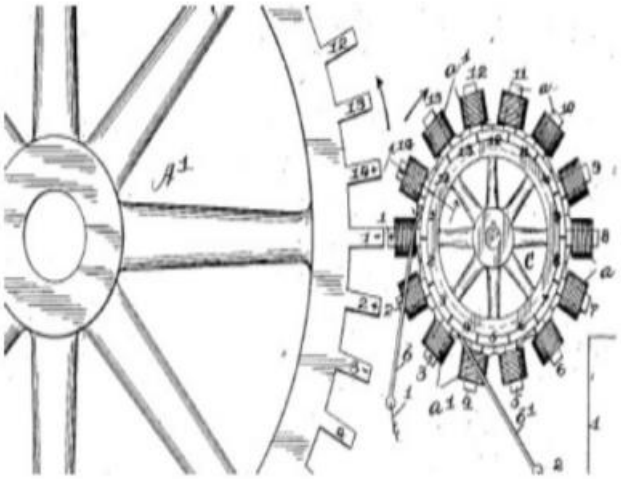

Figure 2.3: First Magnetic Gear

The amount of torque that could be transferred for the volume occupied fell short even the gear had the advantage of contact-less power transfer and low noise operation. At any given moment only one to three electromagnets transferred torque. Slip rings, which caused unnecessary losses and needed high maintenance connected to the electromagnets had to be connected electrically. By applying magnetic force, the power transmission principle in mechanical gear devices is similar as with magnetic gear, except that the gear is not made with teeth meshing but without the contact. The current flowing through the coil windings that are placed on the driving gear teeth obtained magnetic forces.

Neuland [10] invented a far superior magnetic gear in 1916. The gear consisted of three main parts which is a magnetic modulation piece in between the two steel rotors and laminated steel outer- and inner-rotor as shown in Figure 2.4.

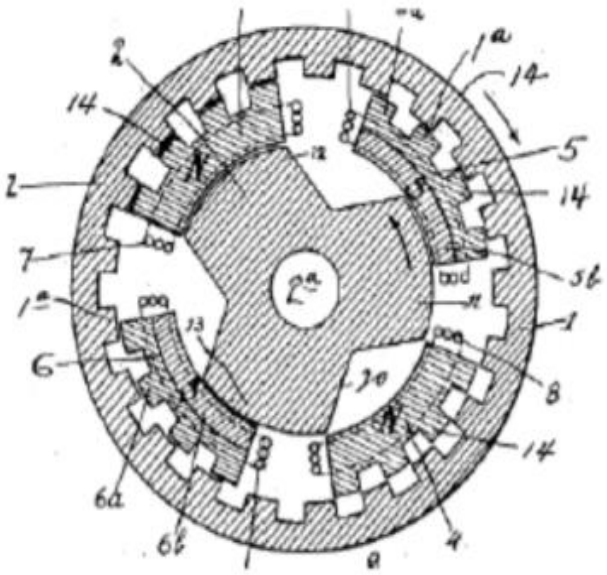

Figure 2.4: Coaxial Magnetic Gear

The inner rotor and the outer rotor saw the correct harmonics in accordance with the number of teeth on each shaft so the modulation pieces were shaped to modulate magnetic flux. The gear ratio between the shafts determined by the ratio of teeth on the outer and inner rotor. Since most of the gear teeth transferred torque at any given moment, the torque density of this configuration was greatly improved compared to the spur-type design from (1).

In 1941, H.T. Faus designed a magnetic spur-type gear [11]. The gear operated in the same way as the electromagnetic spur gear from (1). The only difference was that it used permanent magnets shows in Figure 2.5.

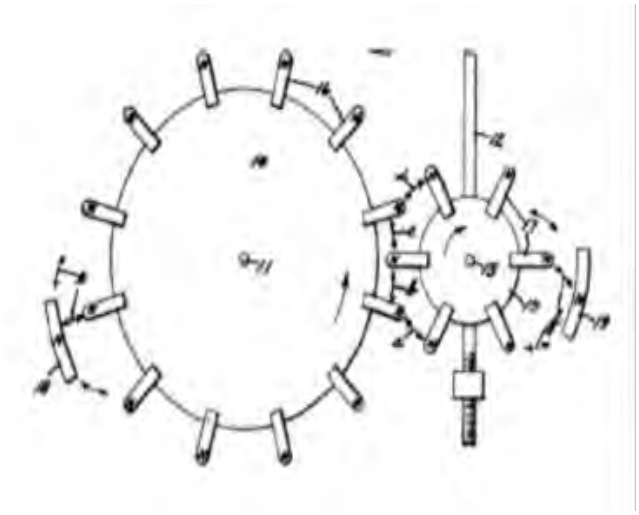

Figure 2.5: Permanent Magnet Spur Gear

The torque was transferred between the shafts by the repulsion of the identical poles of the magnets because all the north poles of the magnets pointed radially outwards. One of the permanent magnets breaks, since the PMs still made contact caused by the maximum torque was exceeded in this design the gear slipped. Thus this design was not suitable when overload protection.

There are concepts of magnetic gears resembling mechanical planetary gears, whose gears rather resemble conventional cylindrical gears (figure 2.6) [9]. Back in 1916, the first reference of a gear without mechanical contact. Magnetic planetary gears were first introduced in the patent [12]. Ackerman had patented its magnetic planetary gear solution given at the end of the 20th century [13]. The first built feasible dates to the 1980s but the only part of magnetic poles was in active magnetic contact and its efficiency was around 25-30% range [14]. A classic gear, which means the mechanical one, which relies on the contact of two wheels or teeth with the different number of iron teeth has some disadvantage. Since then, the magnetic gear was highlighted.