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Design of permanent magnet synchronous motor / Mohd Fadzili Abdul Hamid.

DESIGN OF PERMANENT MAGNET SYNCHRONOUS MOTOR

MOHD FADZILI BIN ABDUL HAMID

Bachelor Of Mechatronic Engineering

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DESIGN OF PERMANENT MAGNET SYNCHRONOUS MOTOR

MOHD FADZILI BIN ABDUL HAMID

A report submitted in partial fulfillment of the requirement for the degree of

Mechatronic Engineering

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2010

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I declare that this report entitle "*Design of Permanent Magnet Synchronous Motor*" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature	:	....
Name	:	Mohd Fadzili Bin Abdul Hamid
I/C No	:	870605-35-5517
Date	:	12th May 2010

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"I hereby declare that I have read through this report entitle "*Design of Permanent Magnet Synchronous Motor*" and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Mechatronic)"

Signature	:	....
Supervisor's Name	:	Fairul Azhar Bin Abdul Shukor
Date	:	12th May 2010

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ABSTRACT

The Permanant Magnet Synchronous motor is a rotating electric machine where the stator is a classic three phase stator like that of an induction motor and the rotor has surface-mounted permanent magnets. In this respect, the PMSM is equivalent to an induction motor where the air gap magnetic field is produced by a permanent magnet. The use of a permanent magnet to generate a substantial air gap magnetic flux makes it possible to design highly efficient PM motors.

The application of high performance of permanent magnet synchronous motors (PMSM) is increasing. However the performence of PMSM are closely related to it structure parameter. PMSM models with accurate parameters are significant for precise control system designs. Acquisition of these parameters during motor operations is a challenging task due to the inherent nonlinearity of motor dynamics.

This project of designing the PMSM is to achieved a few of goals that are to model the PMSM using Solidworks software. It also to have to optimum result or performance by adjusting the parameters which are be the manipulative value in this project. By using FEM technique, this model of PMSM been simulated and FEM been chosen because it can have the complete model to analyze and also can give better result rather than PAM. The generated stator flux together with the rotor flux, which is generated by a rotor magnet, defines the torque, and thus speed, of the motor.

Overall the results were achieved as what had been estimated before the project. The best performance and optimization result had been analyzed using the graph and chart. The method used in this project was absolutely right and the simulation goes smoothly. Magnetic analysis that are the magnetic flux path, magnetic flux density and also meshing been analyze correctly and shows that the simulation gave a good result that will give best result for torque and cogging performance.

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ABSTRAK

Motor magnet kekal segerak ialah salah satu jenis mesin elektrik yang berpusing yang mana ia secaranya klasiknya menggunakan pengekal tiga fasa seperti motor induksi yang lain. Motor ini adalah bersamaan dengan motor induksi di mana jarak angin bermagnet adalah dihasilkan oleh magnet kekal. Penggunaan magnet kekal adalah untuk menghasilkan jarak angin fluks bermagnet di mana di berkemungkinan boleh menghasilkan rekaan motor magnet kekal yang paling efisien.

Aplikasi untuk pelaksanaan paling tinggi bagi Motor Magnet Kekal Segerak (MMKS) adalah meningkat. Walaubagaimanapun, pelaksanaan oleh motor ini berkait rapat dengan struktur parameternya. Model MMKS yang mempunyai parameter paling tepat adalah sesuai dengan rekaan sistem kawalan yang cekap.

MMKS menerima masukan sinus voltan pada kedudukan penggerak. Fluks statik yang terhasil bersama dengan fluks penggerak dimana dihasilkan oleh magnet penggerak adalah kelajuan untuk motor. Dengan menggunakan teknik FEM, model MMKS ini disimulasikan dan FEM pernah dipilih kerana ia boleh mempunyai model lengkap untuk dianalisa dan juga boleh memberikan keputusan lebih baik daripada ‘PAM’. Fluks pemegun dijanakan bersama dengan fluks rotor, yang digenerasikan oleh magnet rotor, menyatakan kilas, dan oleh itu kelajuan tentang enjin.

Keseluruhan keputusan telah dicapai sebagai apa telah dianggarkan sebelum projek ini. Hasil persembahan terbaik dan pengoptimuman telah dianalisis menggunakan graf dan carta. Kaedah yang digunakan dalam projek ini benar-benar betul dan simulasi berjalan dengan lancar. Analisis magnetik yang laluan fluks magnet, ketumpatan fluks magnet dan juga jaringan dianalisa dengan betul dan menunjukkan yang simulasi memberi satu keputusan baik yang akan memberi keputusan terbaik untuk kilas dan penggubalan prestasi.

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CHAPTER 1

INTRODUCTION

An electric motor is a device using electrical energy to produce mechanical energy, nearly always by the interaction of magnetic fields and current-carrying conductors. The reverse processes that using mechanical energy to produce electrical energy will accomplished by a generator or dynamo. Traction motors used on vehicles often perform both tasks [3].

Motor electric is a machine that converts electrical energy into mechanical energy. When an electric current is passed through a wire loop that is in a magnetic field, the loop will rotate and the rotating motion is transmitted to a shaft, providing useful mechanical work. The traditional electric motor consists of a conducting loop that is mounted on a rotatable shaft. Current fed in by carbon blocks, called brushes, and enters the loop through two slip rings. The magnetic field around the loop, supplied by an iron core field magnet, causes the loop to turn when current is flowing through it [16].

Electric motors can be divided into two types and this is the classic division of electric motors that is alternating current (AC) electric motors and direct current (DC) electric motors. A DC electric motor will not run when supplied with AC current, nor will an AC motor run with DC current.

Permanent magnet synchronous motors (PMSM) are widely used in low and mid power applications such as computer peripheral equipments, robotics, adjustable speed drives and electric vehicles. The growth in the market of PM motor drives has demanded the need of simulation tools capable of handling motor drive simulations .

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Simulations have helped the process of developing new systems including motor drives, by reducing cost and time. Simulation tools have the capabilities of performing dynamic simulations of motor drives in a visual environment so as to facilitate the development of new systems [9].

Permanent Magnet Synchronous Motor (PMSM) is a rotating electric machine where the stator is a classic three phase stator like that of an induction motor and the rotor has surface-mounted permanent magnets. In this respect, the PMSM is equivalent to an induction motor where the air gap magnetic field is produced by a permanent magnet. The use of a permanent magnet to generate a substantial air gap magnetic flux makes it possible to design highly efficient PMSM motors [17].

A PMSM is driven by sine wave voltage coupled with the given rotor position. The generated stator flux together with the rotor flux, which is generated by a rotor magnet, defines the torque, and thus speed, of the motor. The sine wave voltage output have to be applied to the 3-phase winding system in a way that angle between the stator flux and the rotor flux is kept close to 90° to get the maximum generated torque. To meet this criterion, the motor requires electronic control for proper operation [17].

For a common 3-phase PMSM, a standard 3-phase power stage is used. The same power stage is used for AC induction and BLDC motors. The power stage utilizes six power transistors with independent switching. The power transistors are switched in the complementary mode. The sine wave output is generated using a PWM technique [17].

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1.1 Problem Statement

Permanent magnet (PM) synchronous motors are widely used in low and mid power applications such as computer peripheral equipments, robotics, adjustable speed drives and electric vehicles.

The growth in the market of PM motor drives has demanded the need of simulation tools capable of handling motor drive simulations. Simulations have helped the process of developing new systems including motor drives, by reducing cost and time. Simulation tools have the capabilities of performing dynamic simulations of motor drives in a visual environment so as to facilitate the development of new systems [18].

PMSM been done in this project to test and simulate the model and to determine whether the best performance can have in this type of model. The problem is that, can the motor get the best results of its performance and it's the best optimization in smaller size of PMSM and can set the lowest cogging for it. In principle, the construction of a permanent magnet synchronous machine does not differ from that of the brushless DC motor (BLDC), although distributed windings are more often used. However, while the excitation current waveform was rectangular with a BLDC, sinusoidal excitation is used with PMSMs, which eliminates the torque ripple caused by the commutation. PMSMs are typically fed by voltage source inverters, which cause time-dependent harmonics on the air gap flux. Permanent magnet synchronous machines can be realized with either embedded or surface magnets on the rotor, and the location of the magnets can have a significant effect on the motor's mechanical and electrical characteristics, especially on the inductances of the machine [19].

The permanent-magnet synchronous motor has not yet evolved as a standard off-the-shelf servo motor, because of the ongoing research for high-energy, permanent-magnet materials with improved magnetic and mechanical properties. Furthermore, the numerous possible configurations for the permanent magnet rotor, has meant that the machine exists in several versions, each with its own unique properties and requiring unique control and power supply arrangements. In this work a sinusoidal permanent-magnet synchronous motor is designed and built with the help of a finite-element based, computer aided design package. An analytical method for determining the forces and electromechanical torques in the machine is developed [20].

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The problem that had to be studied throughout this project is that firstly to design the permanent magnet synchronous motor. This PMSM also will design to increase torque while the cogging will decrease and can get high torque applied to the motor and the need of application of PMSM is increase recently. It also have need to fulfill the high torque requirement and limited space to maintain the PMSM. The example of application of this project is electric vehicle.

1.2 Objective

There are several objectives that can be stated in this project that are :

a. To develop the model of permanent magnet synchronous motor.
b. To simulate the model by using FEM technique
c. To obtain optimum value for taper permanent magnet.

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1.3 Thesis Layout

The thesis is divided into five chapters. The theoretical background, the goals, and the motivation for this work are introduced in Chapter 1. In Chapter 2, the basic principle of the PMSM and literature review is given. Also the design of the PMSM and introduction of all its parts and measurement is introduced in Chapter 2. In Chapter 3, design aspects of an induction motor that have to be adopted to improve its dynamic performance in order to be able to compete with the dynamic performance of the PMSMs are introduced. The most important is the torque of the PMSM and how much cogging that preferred to the motor. Also the materials that build the PMSM also introduced in Chapter 3. Chapter 4 focuses on the design and simulation of the PMSM. By using the FEM software, it simulink the motor to get the real and high torque.

The accuracy of the modeling can be improved, as the model is thereby capable of correctly modeling the effects of the torque and cogging rise on the motor's electric characteristics, such as the resistance variation due to temperature. Chapter 5 provides a summary of the work, and presents ideas for further investigation.

1.4 Scope

The main scope of this project is to model and simulate the PMSM to get the optimum results according to the parameter. It is also to optimize all the parameters that used in this project that are H_t, and L_t while the H_c, and L_c are the parameter used to obtain the value of the coil can may affect the optimum or the best results of torque and cogging of the motor.

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CHAPTER 2

LITERATURE REVIEW

The classic definition, electric machine is synonymous with electric motor or electric generator, which are electro-mechanical energy converters: converting electricity to mechanical power (i.e., electric motor) or mechanical power to electricity (i.e., electric generator). The dynamic movement of the mechanical power can be rotating or linear. Electric machines (i.e., electric motors and electric generators) can be classified as singly-fed electric machines or doubly-fed electric machines, which can be further reduced to asynchronous, synchronous, or reluctance singly-fed or doubly-fed electric machines [2].

2.1 Basic Concept of Electric Motor

The basic concept of an electric motor is that an electric motor is a device using electrical energy to produce mechanical energy, nearly always by the interaction of magnetic fields and current-carrying conductors. The reverse processes that using mechanical energy to produce electrical energy will accomplished by a generator or dynamo. Traction motors used on vehicles often perform both tasks. Electric motors are found in a myriad of applications such as industrial fans, blowers and pumps, machine tools, household appliances, power tools, and computer disk drives, among many other applications [3].

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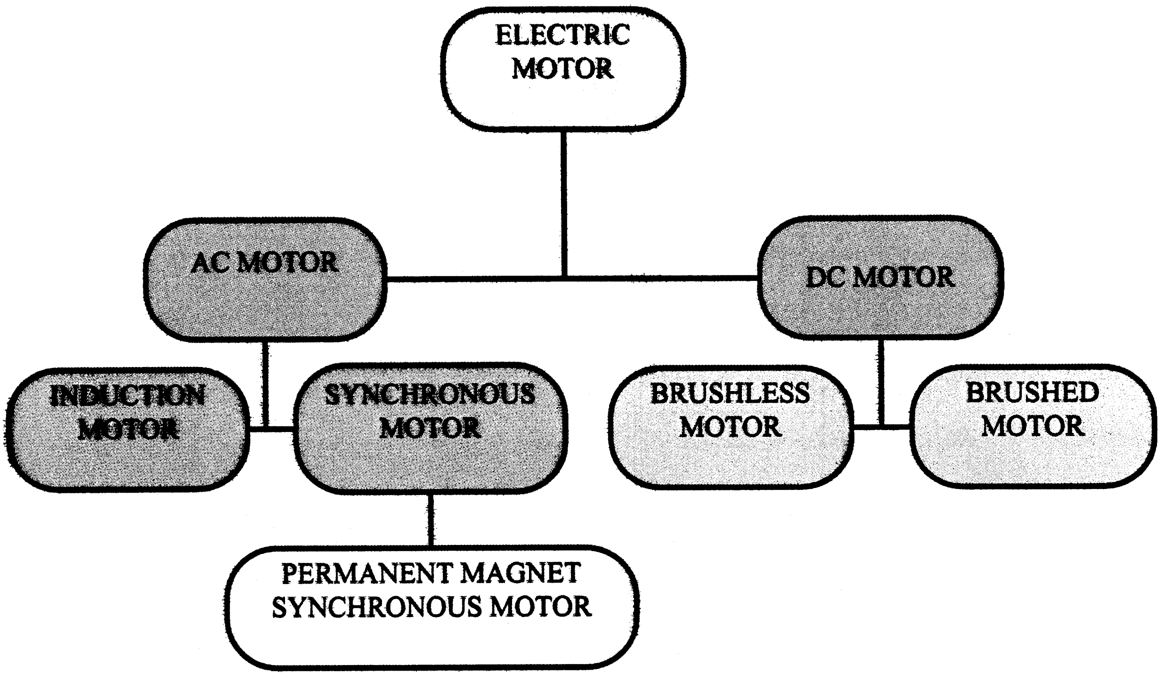

Figure 2.1: Electric Machine Chart

Figure 2.1 shows that group of electric motor which contains two major group which are AC motor and DC motor. Permanent Magnet Synchronous Motor (PMSM) is in the group of AC Motor which is the part of synchronous motor. This kind of machine sometimes can be similar to the brushless DC Motor but then, PMSM use input three phase voltage to itself.

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2.2 Permanent Magnet Synchronous Motors (PMSM)

Permanent Magnet Synchronous Motors (PMSM) are often considered "exotic" or useful only for appliance applications plus perhaps a few niche markets. The reality is that PMSM motors have been gaining significant traction in a number of widely diversified applications [5]. Like all motor types, they have their advantages and disadvantages. PMSM motors have its advantages as in Figure 2.2.

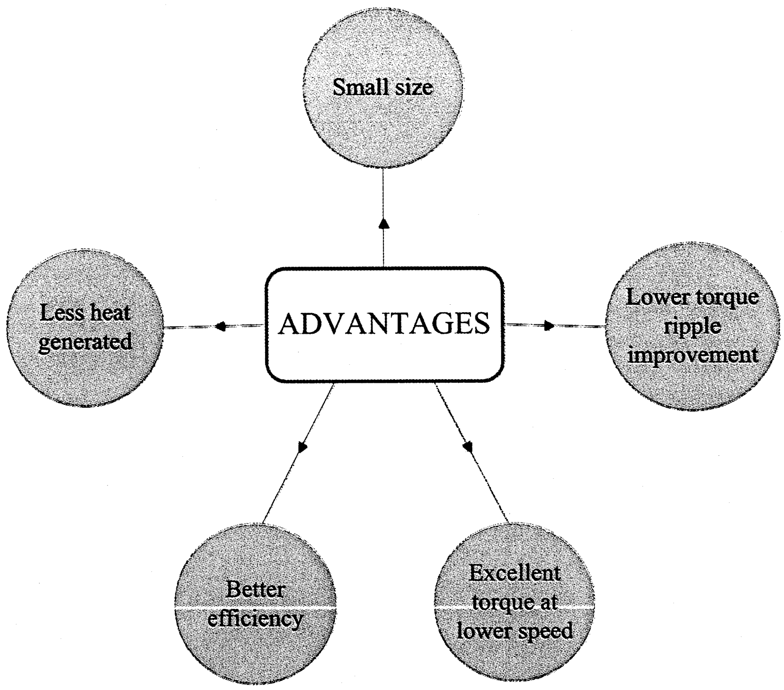

Figure 2.2: Advantages of PMSM

Compared to other electric motor type, PMSM drives offer higher power density which is a magnet can create a magnetic field in a smaller space than would be required for an equivalent field winding. Besides that, higher power factor means that the magnets can be designed to produce operation at unity power factor under rated conditions. PMSM also prefer higher efficiency which there is no rotor currents and also lower stator currents due to improved power factor. In this case, the motor can have the best performance for its load. PMSM is a simple motor that can get more precise control [6].

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Figure 2.3 below tells about those are the disadvantages that might have in this PMSM. The difficulty operating above speed is that the motor have its own input current. If the input current is high then the speed also will get higher and make the flux greater. This can make the torque decrease. The availability of permanent magnet material are less in market especially in Malaysia and if there are, the cost of each magnet are difficult to verify because it depend on the quantity that buyer request to and its make this permanent magnet not so easy to apply [6].

Figure 2.3: Disadvantages of PMSM

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2.3 Basic Principles of PMSM

PMSM can be divided into two major parts that are stator and rotor. The non-rotating is called the stator and the rotating part are usually inside the stator, is called the rotor [10]. Based on the Figure 2.4, recording to the stator, the minor and the important part is the coils that will be winded at the stator. The rotor is the moveable part in this PMSM. In the rotor, it contains the main part that is the permanent magnet. All the parts will be describe and briefly explain in the next figures.

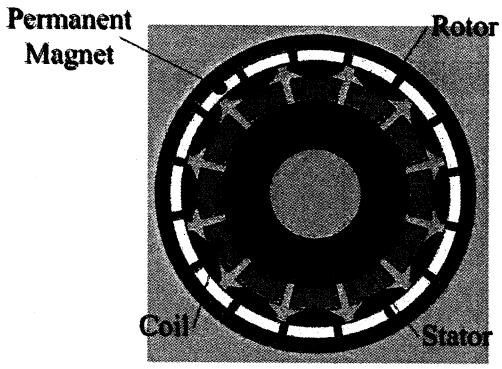

Figure 2.4: Full structure of PMSM

In this PMSM, this stator has 12 slots to wind the coils. This is the stationary part in this motor such as in an electric generator or a mechanical generator. Depending on the configuration of a spinning electromotive device the stator may act as the field magnet, interacting with the armature to create motion, or it may act as the armature, receiving its influence from moving field coils on the rotor [7]. In it operation, this stator are divided into two poles that is north and south poles. Referred to the figure above, it is because it uses to react with the permanent magnet that can give reaction and make the rotor turn.

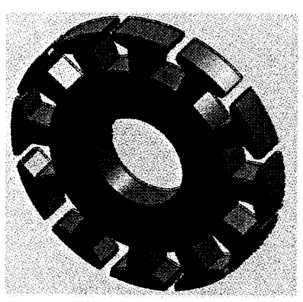

Figure 2.5: Stator of PMSM

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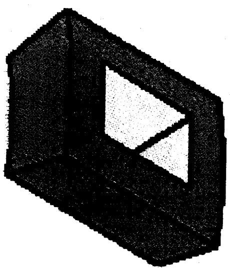
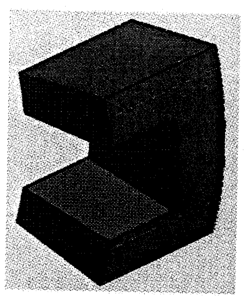
Material that used to make this stator is stainless steel SS400. Stainless steel is an iron-containing alloy-a substance made up of two or more chemical elements-used in a wide range of applications. It has excellent resistance to stain or rust due to its chromium content, usually from 12 to 20 percent of the alloy. There are more than 57 stainless steels recognized as standard alloys, in addition to many proprietary alloys produced by different stainless steel producers. These many types of steels are used in an almost endless number of applications and industries: bulk materials handling equipment, building exteriors and roofing, automobile components (exhaust, trim/decorative, engine, chassis, fasteners, tubing for fuel lines), chemical processing plants (scrubbers and heat exchangers), pulp and paper manufacturing, petroleum refining, water supply piping, consumer products, marine and shipbuilding, pollution control, sporting goods (snow skis), and transportation (rail cars), to name just a few [15].

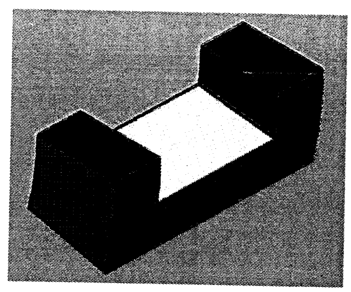
A coil is a series of loops. A coiled coil is a structure where the coil itself is in turn also looping. This PMSM coils have its size and the coils are winding in 12 slot at the stator. The material of coil that be used is made from copper.



(a) : isometric view



(b) : Cross sectional of Front view



(c) : Cross sectional of Top view

Figure 2.6: Coil of PMSM

Rotor is the non-stationary part in electric motor which rotates because the wires and magnetic field of the motor are arranged so that torque is developed about the rotor's axis. In this PMSM design, its rotor is designed to have the permanent magnet in it. So, the rotors have 16 slots to insert the permanent magnet [8].

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Figure 2.7 shows the picture of a rotor that use in this PMSM project. This rotor is designed to be filling by 16 permanent magnet where the magnet are set to be north and south poles. It also used the same material as stator that is using SS400.

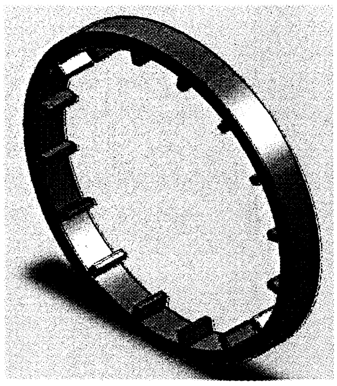

Figure 2.7: Rotor of PMSM

A permanent magnet is an object made from a material that is magnetized and creates its own constant magnetic field [9]. Permanent magnet is made from magnetically hard materials that stay magnetized that call neodymium iron-boron NdFeB. PMSM needs 16 permanent magnets to insert in its rotor. These permanent magnets have its poles which are north and south poles.

Replacing common rotor field windings and pole structure with permanent magnets put the motor into the category of brushless motors. Figure 2.8 shows the permanent magnet that use in PMSM and it is possible to build brushless (PMSM) with any even number of magnet poles. Motors have been constructed with two to 50 or more magnet poles. A greater number of poles usually create a greater torque for the same level of current.

This is true up to a certain point where due to the space needed between magnets, the torque no longer increases. The use of magnets enables an efficient use of the radial space and replaces the rotor windings, therefore suppressing the rotor copper losses. Advanced magnet materials such as Sm_2Co_{17} or NdFeB permit a considerable reduction in motor dimensions while maintaining a very high power density. In the case of embedded systems where the space occupied is important, a PMSM is usually preferred to an AC synchronous motor with brushes [12].

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