A NEW STRUCTURE OF 12SLOT-10POLE FIELD-EXCITATION FLUX SWITCHING SYNCHRONOUS MACHINE FOR HYBRID ELECTRIC VEHICLES

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ABSTRACT

The new structure 12Slot-10Pole-field excitation flux switching synchronous machine (FEFSSM) with all active parts of the field excitation coil (FEC) and the armature coil is located in the stator, used for hybrid electric vehicles (HEVs). Design of the new structure different from the previous design which no permanent magnets. For a high-speed motor applications together with the system coupled with reduction gear, designed the rotor consists of a single piece of iron make it even stronger. The target of the same design specification motor in IPMSM used for LEXUS RX400h with a maximum torque of 210Nm with a 4:1 gear reduction ratio, 123kW maximum power, maximum power density of more than 3.5kW/kg, and a maximum speed of 20,000 r / min. To optimize the design, the design parameters of the rotor, the armature and the FEC changed repeatedly until the target is achieved with a maximum density 30A/mm2 for both the armature and the FEC. The end result after optimizing the design allows the latest designs with the same power density in the IPMSM can be used in commercial SUV-HEV.

ABSTRAK

Struktur baru 12Slot-10Pole bidang-pengujaan fluks pensuisan segerakmesin (FEFSSM) dengan semua bahagian-bahagian aktif iaitu gegelung pengujaan lapangan (FEC) dan angker gegelung adalah terletak di pemegun, digunakan untuk kenderaan elektrik hibrid (HEVs). Rekabentuk struktur baru ini berbeza daripada rebabentuk sebelum ini yang mana tiada magnet tetap. Bagi mendapatkan motor berkelajuan tinggi beserta dengan aplikasi system ditambah dengan gear pengurangan , bahagian pemutar direkabentuk terdiri daripada tunggal sekeping besi menjadikannya lebih mantap. Sasaran spesifikasi rekabentuk motor yang sama dalam IPMSM digunakan untuk LEXUS RX400h dengan tork maksimum daripada 210Nm dengan nisbah pengurangan gear 4:1, kuasa maksimum 123kW, ketumpatan kuasa maksimum lebih daripada 3.5kW/kg, dan kelajuan maksimum 20,000 r / min. Bagi mengoptimumkan rekabentuk, parameter rekabentuk pemutar, angker dan FEC diubah berulangkali sehingga sasaran dicapai dengan ketumpatan maksimum 30A/mm2 bagi kedua-dua angker dan FEC. Keputusan akhir selepas mengoptimumkan rekabentuk membolehkan rekabentuk terkini dengan ketumpatan kuasa yang sama dalam IPMSM boleh digunapakai pada komersial SUV-HEV.

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LIST OF SYMBOLS AND ABBREVIATIONS

SUV	-	Spot utility vehicles
HEV	-	Hybrid Electric Vehicles
ICE	-	Internal Combustion Area
IPMSM		Interior Permanent Magnet
FEFSSM		Field Excitation Flux Switching Synchronous Machine
Fac	-	Field Armature Coil
Fec	-	Field Excitation Coil
Ja	-	Armature Current Density
Arms	-	Armature current
Sa	-	Armature Slot Area
Na	-	No of turn of armature
α	-	Filling factor
Je	-	FEC Current Density
Ae	-	FEC current
Se	-	FEC Slot Area
Ne	-	No of turn of FEC
UTHM		*Universiti Tun Hussein Onn Malaysia*

CHAPTER 1

INTRODUCTION

1.1 Research background

Lately global warming also known as green house effect is the most popular issues that we have to face. It is comes from the emission from the vehicles. Private vehicles demand also increasing proportional to the world populations. Government agencies and organizations have thinks the best method to standards the fuel consumption and emission. Internal combustion engine (ICE) have been use since 100 years ago but it is continue to improve with the aid of automotive electronic technology, which mainly rely on alternative evolution approaches to significantly improve the fuel economy and reduce emission. The researcher finds the solution for this problem with introduce the hybrid electrical vehicles (HEVs). One of the reasons introducing hybrid electrical which wide range full-performance high efficiency vehicles and reduces pollution emission. HEVs operate from combination battery-based electric machines with ICE [1-4].

1.2 Problem statement

The raw material such as Neodymium (*Nd*), Dysprosium (*Dy*) and Terbium (*Tb*) was using in electric vehicles. This material as a additives for indispensable to provide the rare-earth magnet with high coercivity. The production amount of *Nd2Fe14B* would reach at 1,500 tons only in HEV applications in 2011 and the corresponding usage of 70 tons Dysprosium refer to the report released by Mineral Resource Information Center affiliated to Japan Oil, Gas and Metals National Corporation. Effect from that the serious problems are involve costing which increasing the price of raw material, security and difficult to get the supply. Researcher must think the development of permanent magnet machines with less or without rare earth material [13-15]

1.3 Objective

The objective of this design and analysis is:

(i) To design a 12slot-10pole field-excitation flux switching.

(ii) To analyze the motor under no load and load analysis similar restriction and specifications used in Lexus RX 400h.

(iii) To improve the design 12S-10P until maximum performance without any flux source from permanent magnet.

1.4.1 Thesis outlines

(i) Chapter 1, has presented a brief introduction of the project mainly about transmission line and copper cable. It also discusses the problem statements and the objectives of the project to be carried out.

(ii) Chapter 2, will explains more on the literature review about the topic. The study about the past similar project and the historical background of the project is also covered in this chapter. The study includes the software that used in constructing and developing the project.

(iii) The explanation for the method and process involved in making the project including the construction of motor cores is being showed in chapter 3. The description of the method used, and how both being managed, is described in this chapter.

(iv) The result, analysis and discussion will be explained in chapter 4. This chapter will calculate result. In brief this chapter discuss about the initial result compared to improvement result.

(v) Chapter 5 is the presentation of final conclusion of the project and recommendation for future analysis.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction of Synchronous Machines

A synchronous machine is an ac rotating machine whose speed under steady state condition is proportional to the frequency of the current in its armature. The magnetic field created by the armature currents rotates at the same speed as that created by the field current on the stator, which is rotating at the synchronous speed, and steady torque results.

2.2 Review on electrical motors used in HEV

There are four types of electric machines using for HEVs such as direct current (dc) machines, induction machines, switch reluctance (SR) machines, and permanent magnet brushless (PM BL) machines.

Simple control of the orthogonal disposition of field and armature mmf is benefit have in DC machines as EVs and HEVs. Efficiency of the motor will reduce while replacing field winding with PMs in stator. Commutation of DC machine is improved but armature reaction is reduced effect of permeability of PMs. Dc drive moving depends on commutators and brushes, makes them less reliable and unsuitable for a maintenance-free operation.

Induction machines are operated using the brusher with low cost, high reliability, and freedom from maintenance. This machine was controlling using variable voltage variable frequency (VVVF). VVVF itself not give the desired performance.

The induction machine is due to the nonlinearities of their dynamic model. The principle of field-oriented control or vector control of induction drives has been adopted to overcome their nonlinearities. The continually fueled by new design approaches and advanced control strategies are the development of induction machines in EV and HEV [5].

The advantages of Switch Reluctant (SR) machines are simple construction, low manufacturing cost, and outstanding torque-speed characteristics. From the advantages it has been accepted to have a considerable potential for HEVs. Acoustic-noise, design and control are difficult are the problems of this machines [6-8].

On the other hand, PM BL machines are becoming more and more attractive and can directly compete with the induction machines for HEVs. The advantages of PM BL machines are their inherently high efficiency, high power density, and high reliability. The main problem is their relatively high cost due to PM materials. In general, according to the operating current and no-load electromotive-force (EMF) waveforms, they are classified as PM BL ac (BLAC) and PM BL dc (BLDC) types. In recent years, the class of PM BL drives has been expanded to attract those with hybrid field excitations [9]. The major requirements of HEVs electric propulsion, as mentioned in past literature, are summarized as follows:

(i) highest instant power and highest power density
(ii) high torque at low speed for starting and climbing, as well as high power at high speed for cruising
(iii) very wide speed range, including constant-torque and constant-power regions
(iv) fast torque response
(v) high efficiency over the wide speed and torque ranges
(vi) high efficiency for regenerative braking
(vii) high reliability and robustness for various vehicle operating conditions
(viii) reasonable cost

2.3 IPMSM used in HEV

The development of electric machines for HEVs is interior permanent magnet synchronous machines (IPMSMs) which have been employed mainly to increase the power density of the machines [10-11]. This can be proved by the historical progress in the power density of main traction motor installed on Toyota HEVs. The power density of each motor employed in Lexus RX400h'05 andGS450h'06 have been improved approximately five times and more, respectively, compared to that installed on Prius'97 [12]. Although the torque density of each motor has been hardly changed, a reduction gear has enabled to elevate the axle torque necessary for propelling the large vehicles such as RX400h and GS450h. As one of effective strategies for increasing the motor power density, the technological tendency to employ the combination of a high-speed machine and a reduction gear would be accelerated.

2.4 Classifications of Flux Switching Machine (FSM)

Generally, the FSMs can be categorized into three groups that are permanent magnet flux switching machine (PM), field excitation flux switching machine (FE), and hybrid excitation flux switching machine (HE). Both PM and FE has only PM and field excitation coil (FEC), respectively as their main flux sources, while HE combines both PM and FEC as their main flux sources. Fig. 2.1 illustrates the general classification of FSMs. For this thesis we concentrate more than for field excitation flux switching machine (FEFSM**).**

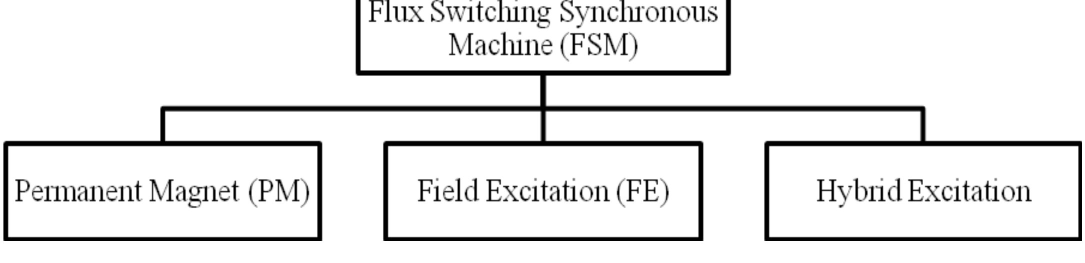

Figure 2.1 : General classification of FSMs.

2.4.1 Field Excitation Flux Switching Machine (FEFSM)

Combination principles of the inductor generator and the SRMs a novel topology of FEFSM is a form of salient-rotor reluctance machine [16-18]. The design of FEFSM applications need required high power densities and a good level of durability which the concept of the FEFSM involves changing the polarity of the flux linking with the armature winding, with respect to the rotor position. The novelty of the invention was that the single-phase ac configuration could be realized in the armature windings by deployment of DC FEC and armature winding, to give the required flux orientation for rotation. The torque is produced by the variable mutual inductance of the windings. The single-phase FEFSM is very simple motor to manufacture, coupled with a power electronic controller and it has the potential to be extremely low cost in high volume applications. Furthermore, being an electronically commutated brushless motor, it inherently offers longer life and very flexible and precise control of torque, speed, and position at no additional cost.

The operating principle of the FEFSM is illustrated in Fig. 2.2. Fig. 2.2(a) and (b) show the direction of the FEC fluxes into the rotor while Fig. 2.2(c) and (d) illustrate the direction of FEC fluxes into the stator which produces a complete one cycle flux. Similar with PMFSM, the flux linkage of FEC switches its polarity by following the movement of salient pole rotor which creates the term "flux switching". Each reversal of armature current shown by the transition between Fig. 2.2(a) and (b), causes the stator flux to switch between the alternate stator teeth. The flux does not rotate but shifts clockwise and counter clockwise with each armature-current reversal. With rotor inertia and appropriate timing of the armature current reversal, the reluctance rotor can rotate continuously at a speed controlled by the armature current frequency. The armature winding requires an alternating current reversing in polarity in synchronism with the rotor position. For automotive applications the cost of the power electronic controller must be as low as possible. This is achieved by placing two armature coils in every slot so that the armature winding comprises a set of closely coupled (bifilar) coils.

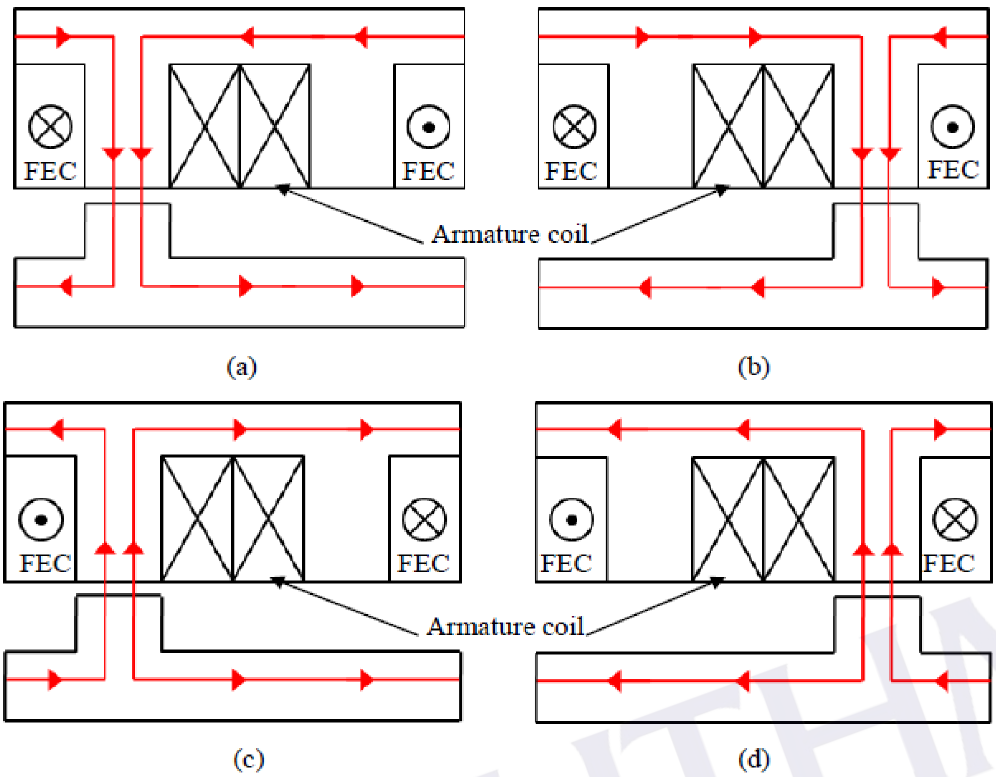

Fig. 2.2: Principle operation of FEFSM (a) θ*e*=0° and (b) θ*e*=180° flux moves from stator to rotor (c) θ*e*=0° and (d) θ*e*=180° flux moves from rotor to stator

The advantages and disadvantages of FSM discussed in this chapter are listed in Table 2.1.

Table 2.1: Advantages and disadvantages of FSM

Advantages	Disadvantages
1. Simple design and robust rotor structure suitable for high speed applications 2. Easy to manage magnet temperature rise as all active parts are located in the stator 3. Flux focusing / low cost ferrite magnets can also be used 4. Sinusoidal back-emf waveform which is suitable for brushless AC operation	1. Reduced copper slot area in stator 2. Low over-load capability due to heavy saturation 3. Complicated stator 4. Flux leakage outside stator 5. High magnet volume for PMFSM

2.5 Types of losses in synchronous machine

2.5.1 Copper loss

Whenever current flows in a conductor, power is dissipated in the resistance of the conductor in the form of heat. The amount power dissipated by the conductor is directly proportional to the resistance of the wire, and to the square of the current through it. The greater value of resistance or current, the greater is the power dissipated.

The core of a machine is usually constructed of some type of ferromagnetic material because it is a good conductor of magnetic line of flux. This magnetic field cuts the conducting core material and induces a voltage into it. The induce voltage causes random currents to flow the core which dissipated power in the form of heat. These undesirable currents are called eddy currents. The eddy current produced due to the resistive nature of the core and hence edy current loss is proportional to the square of the current in the wining.

2.5.2 Building factor

Building Factor is obtained by dividing the actual core loss perunit by the nominal material loss per unit. There are several parameters which have an effects on the building factor:

(i) Geometry

(i) Material

(ii) Characteristics

(iii) Stress

2.5.3 Core loss

Core loss (or iron loss) is a form of energy loss that occurs in electrical machine and other inductors. The loss is due to a variety of mechanisms related to the fluctuating magnetic field, such as eddy currents and hysterisis. Most of the energy is realed as heat, through some may appear as sound. Core losses do not include the losses due to resistance in the conductors of the windings, which is often termed copper loss.

2.5.4 Hysterisis loss

When a magnetic field is passed through a core, the core material becomes magnetized. To become magnetized, the domains within the core must align themselves with the external field. If the direction of the field is reversed, the domains must turn so that their poles are aligned with the new direction of the external field.

2.6 Types of iron (steel)

Each type of iron (steel) has maximum flux density it can be run at without saturating. The designer refers to B-H curves for each type of steel. They select a flux density where the knee either starts on the curve, or slightly up on it. This will give a machine with the lowest weight possible for that material. The curve show in Figure 2.3 that as saturation begins the magnetic field strength in oversets (H) raises rapidly as compared to any increase in flux density (B). When using the equations, the two most important are the number of turns (N) and the core area (a). One needs to find the core area is square centimeters or inches, and match it to the total power in watt or volt-amperes. The larger the core, the more power it will handle. Once this core size is calculated, one then fids the number of turns. One then is looking at a machine will cause a flux density of a specified amount due to the number of turns in a certain type/size of core

The ideal design objective is to minimize the no-load losses and the load losses. If the no-load losses equal the load losses, the machine has reached the ideal design to minimize losses. This is usually done by reducing core losses through the reduction in core flux density. However, reducing the core flux density to reduce core losses requires more conductor turn and increase load losses. Likewise, if the load density is lowered, more core material will be required, which will increase no-load losses. Machine design reduces losses in a compromise weighing the distribution of losses in the core and coils with the weigh, size, volume, impedance, insulation and cost of machine.

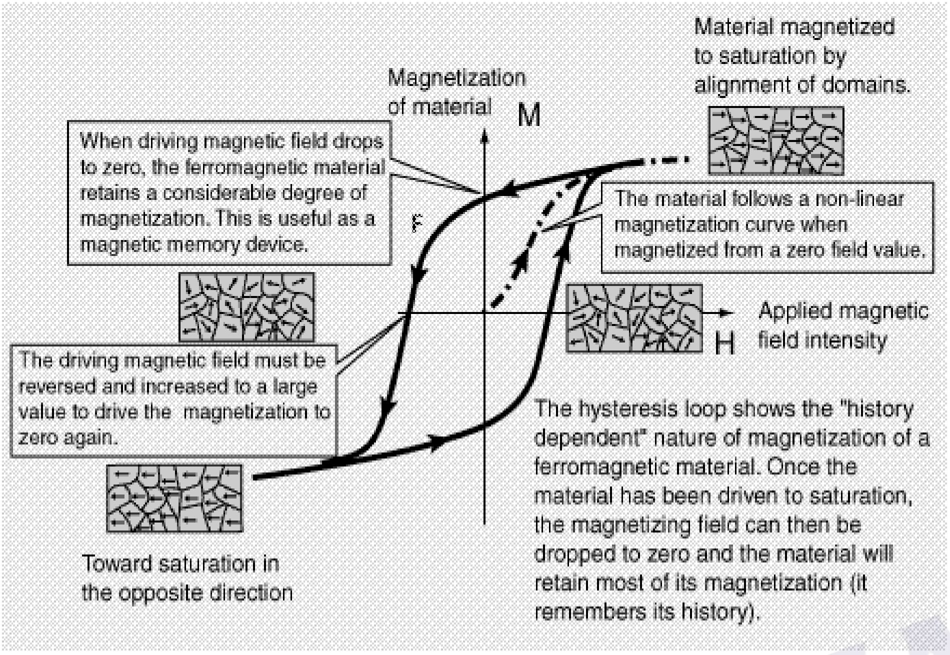

Figure 2.3: Hysteresis Loop

2.7 JMAG Software

In designing the AC motor, JMAG software is used because JMAG is simulation software for electromechanical design and development. JMAG was originally release in 1983 as a tool to support design for devices such as motors, actuators, circuit component, and antennas.

The design of a rotating machine requires that the outcome of deploying magnetomotive force from coils or permanent magnets is predictable so the figures for torque and other aspects of machine performance can be produced. Traditionally a wealth of experience built up by designers incorporating the known properties of electrical steels and other materials has been incorporated into computer programs and expert systems to aid design. This process works well but may not be placed to most advantageously take account of the properties of new materials or to devise routes towards new machine performance demands. The growing use of permanent magnets and operational current waveform synthesized from multipulse inverters poses new design challenges.

The physical phenomena associated with electromagnetism can be described in terms of a set of partial differential equations which describe the structure and

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