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MODELLING OF SUSPENSION AND MOTORING FORCE FOR BEARINGLESS PERMANENT MAGNET SYNCHRONOUS MOTOR

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MODELLING OF SUSPENSION AND MOTORING FORCE FOR BEARINGLESS PERMANENT MAGNET SYNCHRONOUS MOTOR

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DEDICATION

To my beloved mother and father

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Electrical Engineering (Power Electronics and Drives).

Signature : ……………………………….

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Date : ……………………………….

ABSTRACT

Bearingless permanent magnet synchronous motor (PMSM) is the combination of the characteristic of conventional permanent magnet synchronous motor with magnetic bearing. It is a kind of high performance motor because having both advantages of PMSM and magnetic bearing such as no friction, high speed and long operating life. It is also suitable for high speed application such as compressor, turbines and pump. The purpose of this research is to modelling of motoring torque and suspension force for bearingless permanent magnet synchronous motor by using Maxwell 2D of ANSYS Finite Element Method (FEM). The designed bearingless PMSM consist of two sets of stator winding namely motoring torque winding and suspension force winding. Bearingless PMSM is developed by using the method of suspension force and the mathematical model of electromagnetic torque and suspension force. This mathematical model is built by using Simulink/Matlab and the other parameter values such as current, voltage, airgap length and force are identified. The relationship among configuration of windings, radial suspension force and current are complicated, so finding these relationship is important for modelling the bearingless PMSM. The final suspension force result obtained is compared between FEM and Matlab. Then by using Matlab, the controller for bearingless PMSM is developed to realize the controllable of rotor that consist of position controller and speed controller. This research covered the principle of suspension force, the mathematical model, Proportional Intergral (PI) control system of bearingless PMSM and also FEM analysis. Finally, the recommendation for future research studies is included to improve the research on bearingless PMSM.

ABSTRAK

Motor magnet kekal segerak tanpa galas (BPMSM) adalah gabungan ciri-ciri konvensional motor magnet kekal segerak dengan galas bermagnet. Ia adalah sejenis motor berprestasi tinggi kerana mempunyai kedua-dua kelebihan PMSM dan galas bermagnet seperti tiada geseran, kelajuan tinggi dan jangka hayat yang panjang. Ianya juga sesuai untuk aplikasi kelajuan tinggi seperti pemampat, turbin dan pam. Tujuan kajian ini adalah untuk permodelan tork permotoran dan daya penggantungan untuk motor magnet kekal segerak tanpa galas dengan menggunakan Maxwell 2D ANSYS Kaedah Unsur Terhingga (FEM). Rekabentuk PMSM tanpa galas terdiri daripada dua set penggelungan pemegun diberi nama penggelungan permotoran tork dan penggelungan daya penggantung. PMSM tanpa galas ini dibina dengan menggunakan kaedah kuasa penggantungan dan membina model matematik untuk daya kilas elektromagnet dan daya penggantungan. Model matematik ini dibina dengan menggunakan Matlab/Simulink dan parameter lain seperti arus, voltan, panjang jurang, dan daya dikenalpasti. Hubungan antara konfigurasi penggulungan, daya penggantungan jejarian, dan arus adalah rumit, jadi pencarian hubungan ini penting untuk model PMSM tanpa galas. Keputusan akhir daya penggantung yang diperolehi dibandingkan antara FEM dan Matlab. Kemudian dengan menggunakan Matlab pengawal untuk motor magnet kekal segerak tanpa galas dibina untuk merealisasikan pemutar dikawal yang mana terdiri daripada pengawal kedudukan dan pengawal kelajuan. Kajian ini meliputi prinsip kuasa penggantungan, model matematik, system kawalan digital PMSM tanpa galas dan analisis FEM. Akhirnya, cadangan untuk kajian pembelajaran akan datang dimasukkan untuk meningkatkan kajian terhadap model PMSM tanpa galas.

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D	-	Damping coefficient of viscous friction
F_x	-	Force generate by *x*-axis
F_y	-	Force generate by *y*-axis
i_{ma}, i_{mb}, i_{mc}	-	current for motoring torque at *abc*-phase
i_{sa}, i_{sb}, i_{sc}	-	current for suspension force at *abc*-phase
J	-	Motor shaft inertia
K_M	-	Maxwell Constant
K_L	-	Lorentz Constant
l_m	-	Permanent magnet thickness
l_g	-	Airgap length
M'	-	Mutual inductance
n_m	-	Number of turns for motoring torque winding
n_s	-	Number of turns for suspension force winding
P_m	-	Pole pair number for motoring torque
P_s	-	Pole pair number for suspension force
τ_L	-	External load torque
W_m	-	Magnetic energy
Ψ_{md}	-	Flux Linkage of motoring torque at *d*-axis
Ψ_{mq}	-	Flux Linkage at motoring torque at *q*-axis

LIST OF PUBLICATIONS

Normaisharah Mamat, Kasrul Abdul Karim, Zulkiflie Ibrahim, "*A Review of Design and Analysis of Bearingless Permanent Magnet Synchronous Motor*", Prosiding Seminar Hasil Penyelidikan Sektor Pengajian Tinggi 2013, No. 39, pp. 404-414, 2013

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CHAPTER 1

INTRODUCTION

1.0 Introduction

This chapter gives a brief explanation about the research project on modelling of suspension and motoring force for bearingless permanent magnet synchronous motor (PMSM). It is consist of project background, project motivation, problem statement, objective, and scope. Besides that, the contributions of this research by comparing them with other researches are included in this part. Lastly, the description of the content for each chapter is presented.

1.1 Project Background

A bearingless motor is a new type of motor that produces high speed performance and is the hybrids of magnetic bearings with electric motor. This research is focused on modelling and of suspension and motoring force for bearingless permanent magnet synchronous motor. The term of bearingless permanent magnet synchronous motor is obtained from the combination of conventional permanent magnet motor with magnetic bearing. Bearingless PMSM has both advantages characteristic of PMSM and magnetic bearing. The advantages of PMSM are great power density and high efficiency while advantages for magnetic bearing are no pollution, long life span and require little maintenance. The combination of magnetic bearing with this type of electric motors helps the rotor to suspend in the airgap based on the electromagnetic forces is generated by the magnetic bearings.

For this reason, the principle of radial suspension force is studied. Two sets of winding embedded at the stator which is known as torque winding and radial suspension force winding. The suspension force winding makes the magnetic field in air gap becomes unbalanced and generated both electromagnetic torque and radial suspension force. In order to get the stable rotor the mathematical model is developed. It is to make sure the position of rotor does not touch the inner stator.

There are two important equations that must be developed which is electromagnetic torque equation and the second equation is radial suspension force equation. These equations later are realized in Matlab/Simulink. Another simulation software that used in modelling of suspension force and motoring torque for bearingless PMSM is Finite Element Method (FEM) in 2-Dimensional model. This software is used to calculate the parameter of interest especially the force value at each point. In this research, the FEM simulation is used to obtain the equation that related with the force, radial displacement distance and current windings. Two models have been developed namely independent suspension force model and bearingless PMSM model. This design model is realized by using the exact mathematical equation. Because of the suitability application in high speed machines, bearingless PMSM is used in centrifugal machines, flywheel power storage and pumps.

1.2 Project Motivation

Bearingless motor is widely been studied nowadays due to its advantages in high speed machines. Many types of bearingless motor have been developed such as bearingless PMSM, bearingless induction motor, bearingless brushless DC motor and bearingless switched reluctance motor. In this research the bearingless PMSM is been focused due to its advantages such as high efficiency, reliable operation, less friction and simple structure especially for high speed application.

1.3 Problem Statement

It is difficult to build a magnetic bearing using permanent magnets due to the limitation imposed by Earnshaw's theorem. Most of the magnetic bearings needs continuous power input and active control systems to hold the load stable and make the system becomes complexity. For that reason, the magnetic bearings require a backup bearing in case the failure of power or control system. There are two sorts of instability that are typically present with the magnetic bearings which is attractive magnets give an unstable static force, decreasing with greater distance and increasing at closing distances while second, the conservative force formed by magnetism, in and of itself, gives little damping and oscillations will cause loss of successful suspension if any driving forces are present such as load disturbance and variation in total load inertia.

Besides, bearingless PMSM is a typical complicated system due to the characteristic of nonlinear, multivariable, time-variable and strong couple system. However the existing mathematical model that obtained from virtual displacement method and Maxwell stress tensor method are unable to reflect the dynamic coupled relation between the electromagnetic torque and radial suspension force. Therefore it is difficult to establish the accurate mathematical model of bearingless PMSM by using traditional mathematical model which the two sets of the windings are separately calculated as two independent systems without considering their nonlinear electromagnetic coupling. It causes the undesirable accuracy of the mathematical model. Therefore it is important to develop a bearingless PMSM topology using Maxwell 2D of ANSYS Finite Element Method (FEM). However, with exact mathematical model of radial suspension force and motoring torque can realized the modelling of bearingless PMSM.

1.4 Research Objective

1) To develop a mathematical model of forces and motoring torque for bearingless permanent magnet AC motor.
2) To analyse and validate the force calculate by FEM with mathematical modelling applied in MATLAB.

1.5 Scope of Research

This project is focuses on the development of mathematical model that relates with the current, voltage, *x-y* displacement, radial suspension force and other important parameters for bearingless PMSM. The mathematical model is used to simulate the motor and its controller for speed and position in Matlab/Simulink that shown in Chapter 3. Besides, finding the suspension force and motoring torque force by using the model from FEM 2-Dimensional model is an important aspect in designing bearingless PMSM in Matlab. However this research project does not include the construction of physical machine and hardware because of the limitation of time.

1.6 Contribution on Research

Many types of bearingless motor have been proposed by researchers such as bearingless induction motors, bearingless reluctance motors, and bearingless reluctance motors. Some of the researchers choose bearingless type of permanent magnet due to the advantages and simple structure. The same principle of radial suspension force is used to levitate the rotor and the same mathematical model for electromagnetic torque and suspension force is used. However, most of the researchers control the motor in both operations simultaneously which are rotating and levitating the rotor.

One of the contribution is done by designing the suspension force motor model independently which is controlled the levitation of the rotor to obtain the desired position using mathematical model. To operate the motor in both operations for suspension force and motoring torque, both motoring winding and suspension winding are excited by separating the controller. Finally the complete design of bearingless PMSM is achieved by using Matlab.

The second contribution is the motor model is supplied with difference sources to the motor design. The current source is supplied to the windings of suspension force while the voltage source is supplied to the motoring torque windings.

The third contribution is done by comparing the result that obtained from FEM and Matlab/Simulink simulation. The comparison is based on the relationship of suspension force and radial displacement that produce by both.