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Design to modeling of Permanent Magnet Motors

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Abstract : We present a general procedure for the design of permanent magnet synchronous. This method based on analytical model is checked by a Finite Element Analysis. After, an appropriate model of PMSM is developed. The proposed model enables to take account of all non-ideal characteristics of this machine such as cogging torque, ripple torque. Knowing that torque smoothness is an essential requirement in a wide range of high performance motion control applications, this model can be used to study controller based techniques for minimising pulsating torque. Usually the design of machine is based of steady state, for news applications, it is important to consider dynamics aspects.

Keywords : Permanent magnet, modeling, design, Simulink, Finite Element Analysis

Topic Number : 6 (Theory, Modeling, Simulation)

1 Introduction

Permanent magnet synchronous motors (PMSM) are widely applied in industrial and robotic applications due to their high efficiency, low inertia and high torque-to-volume ratio.

Nevertheless, an inherent drawback is the pulsating torque caused by stator and rotor anisotropy, non sinusoidal distributions of the stator electromotive force and permanent magnet flux density. This torque fluctuation causes vibrations and deteriorates the performance, it has become important to evaluate and reduce torque pulsating.

The main objective of this paper is on the one hand to define a design procedure of permanent magnet synchronous motor and on the other hand to model motor studied in order to apply different control.

For this purpose, we present a design procedure that can be applied to surface-mounted PM (SPM) combined with Finite Element Analysis (FEA), which enables to compute magnetic and electromagnetic characteristics. A data-processing program based on an analytical model and algebraic equations has been developed. The basic objective is to relate the operational requirements of permanent magnet motors to their dimensions, shapes...For that, program makes a link between the mechanical, magnetic, electric and thermal characteristics of the motor.

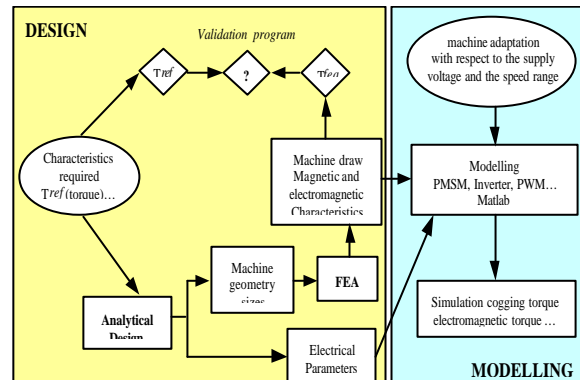
A field calculation code called EFCAD [1] based on the finite element method has been used to compute the electromagnetic characteristics of the rotor. This code permits a simulation of the motor rotation. The rotor motion is taken into account by means of the moving band technique. This stage is based on the numerical resolution of the Maxwell's equations and makes it possible, moreover, to validate the sizing design by means of field calculation. Moreover, it allows the determination of the electromagnetic characteristics such as: flux, inductance, cogging torque (characteristics used for simulation under Matlab/Simulink). A schematic of a methodology is illustrated opposite.

Knowing the precise characteristics of the motor, the modelling and study of dynamic operation with the adequate laws of command can be performed.

Principal interest in this part is that the proposed model takes account of all non-ideal characteristics of the machine such as cogging torque, ripple torque. Knowing that torque smoothness is an essential requirement in a wide range of high performance motion control applications, this model of motor can be used to study controller based techniques for minimising pulsating torque.

2 Design procedure

In this section, we present some design relationships for sinusoidal fed PM motors. PM motors using neodymium-iron-boron (NdFeB) magnets are particularly well suited for high performance. NdFeB magnet is defined by B_r residual flux density and μ_r relative permeability of the magnet. The studied structure presents a radial magnetisation component into a slotted stator. The stator windings are assumed to be nearly sinusoidal distributed. From expression of the electromagnetic torque developed by the interaction of PM field and currents and considering the law of conservation of



field, it is possible to determine the analytical expressions of the motor connecting different parameters (number of poles, winding factor, residual flux density of magnet...) to size of the machine [2].

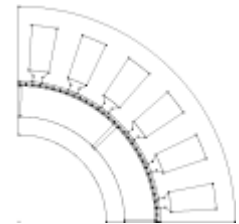
All the magnetic and electromagnetic characteristics such as synchronous inductance, field, torque...computed by FEA are given to one conductor per slot and per phase. The stator resistance per phase can be derived from calculation of the stator winding loss.

The design is based on the torque and determines the total current in the slot. The design must be finally supplemented by calculating the number of conductors per slot, so as to do the machine adaptation with respect to the supply voltage and the speed range. In this way, number of conductor will be calculated compared with the DC voltage source, PWM and the speed required.

A thermal model has been developed in order to make provision for the cooling system of the motor so as to conduct away the total power losses in the steady state without exceeding the temperature limits of the machine materials.

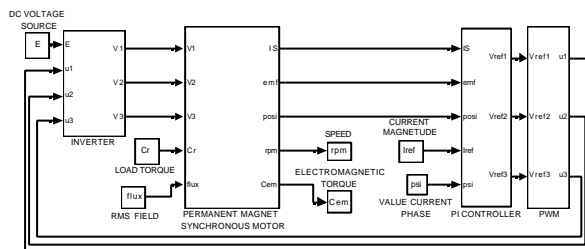
In the full paper, we present all the analytical equations, the results of FEA.

Knowing the precise characteristics of the motor, it is possible to model the motor under MATLAB/Simulink [3] and to study his dynamic operation with the adapted control laws.



3 Analytical models

The motor considered in this paper is a surface-mounted three-phase PM synchronous motor, which consists of three-phase stator windings and a PM rotor. The stator voltage equation is described in the *abc* frame [4]



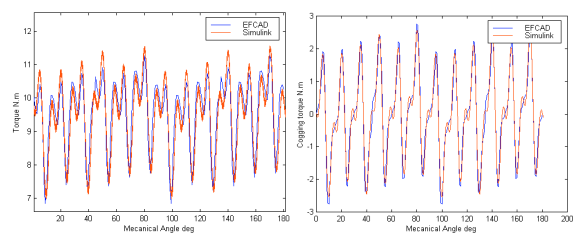
A schematic of a brushless motor drive is illustrated opposite. It includes the inverter, the electrical motor and the current control system [5]. Sinusoidal phase currents are typically developed using a current-regulated inverter that requires individual phase current sensors and a high resolution rotor position sensor to maintain accurate synchronisation of the excitation waveforms with the rotor angular position at every time.

The pulsating torque in a permanent magnet synchronous motors (PMSM) can be separated into three components : the cogging torque, ripple torque and reluctance torque ripple. Electromotive force waveform in this kind of machine is generally non sinusoidal due to the magnet shape and the existence of stator slots. For this reason the Simulink representation must be specially defined.

In final paper, each torque component will be separately presented, some details for each of them will be given. In order to simulate and to devise control techniques that take account of the mentioned effects, an appropriate model of PMSM is developed

4 Simulations and results

In this section, the results of simulation by FEA and by Matlab/Simulink will be presented in this section. For example, we study the behaviour of the proposed structure at no load in order to determinate the cogging torque. The fundamental torque chosen for design is 10 N.m. Opposite, we can notice the electromagnetic torque and cogging torque calculated by FEA and Simulink.



5 Conclusions

In this paper are presented approximate relations for determining the motor size to meet a design specification of electromagnetic torque. These relations are checked by a finite element analysis and enable to determinate geometry, magnetic characteristics of the motor. After, thanks to developed model under Matlab/Simulink, it is possible to represent the pulsating torque and to establish a link between the characteristics of the inverter supply of the motor and the motor, so as to do the machine adaptation with respect to the supply voltage and the speed range. This paper enables to design and to model PMSM for statics and dynamics consideration.

6 References

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