Influence of permanent magnets geometry on cogging torque in a synchronous motor

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Abstract

This paper presents a short comparison of different Permanent Magnet Synchronous Motor geometries and their influence on maximum cogging torque value. It also presents capabilities of Comsol and Matlab in designing aspect. The motor that was chosen is a Surface Permanent Magnet Synchronous Motor with 6 pole pairs and 36 slots. The assumed motor can be used in Electric Vehicle Drive Systems. All the simulations, solving problem, postprocessing and visualizations, were carried out in Matlab. The geometry was made in Comsol combined with Autocad.

1. Introduction

Cogging torque results from the interaction of permanent magnet MMF (Magneto Motive Force) harmonics and the air gap permeance harmonics due to slotting. It manifests itself by the tendency of a rotor to align in a number of stable positions even when the machine is unexcited, and results in a pulsating torque, which does not contribute to the net effective torque. However, since it can cause speed ripples and induce vibrations, particularly at small load and low speed, its reduction is usually a major design goal [4]. According to the nowadays tendencies Permanent Magnet Synchronous Motors seem to be a very attractive group of Electric Motors, because of their high torque value, small dimensions, high speed capabilities and very high efficiency in whole speed range [1, 2, 7]. They are also simpler to be controlled compared to induction motors. This advantages over other electric motors are achieved due to development in PM (Permanent Magnet technology which results in higher parameters and decreased price.

In many demanding industrial applications (in slot milling process, in electric drive for vehicles), there is a requirement of small mechanical torque ripples. It can be achieved both by proper control algorithms with appropriate current control strategies [5], but also by special geometry of a magnetic circuit. Many engineers all over the World deal with the problem of minimization of a current ripple while other get to the same problem but form the other side. One factor of a proper geometry design is the correct shape and volume of permanent magnets. Although there are many articles touching this problem [1, 4], this paper also presents an algorithm for solving the problem starting from designing the motor geometry and calculating physical variables such as magnetic flux density or cogging torque ending on visualization and postprocessing. Cross section of the motor that is considered in this paper and also static magnetic flux density of a motor is presented in the following figures.

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2. PMSM model

The designed motor is a SPMSM (Surface Permanent Magnet Synchronous Machine), and permanent magnets are bonded on the rotor. Such construction is simpler in production, but
mechanically limits rotational speed of a motor (or generator).

Slots are semi-closed oval slots. Magnets are bonded Samarium Cobalt magnets with a remanence induction of 0.97 T.

It had been decided that the presented motor's model's diameter of the stator and the rotor diameter are 130 mm, 65mm, respectively, the axial length is 35 mm; the stator slot openings are 2.6 mm. Air gap space length equals 1mm. The motor has 6 pole pairs and 36 slots. The model was divided into 1013 subdomains and five different material groups and meshed into 163675 elements using standard meshing method with triangular polygons.

3. Comsol and Matlab in modeling, calculations, visualization and postprocessing

There are several well-known commercial programs for field analysis of electric machines, for example: Maxwell, Flux, Comsol. Comsol Multiphysics programming language can be combined with Matlab command line language. Geometry modeling, meshing, PDE problem definition, computing the solution, and performing visualization and postprocessing. The benefits that comes from using Matlab script based modeling are:

-Enhanced productivity through convenient and flexible interaction with Comsol Multiphysics graphical user interface (shorter time of modeling and optimization)

-Additional possibilities for parametric studies (for instance in the case of geometry optimization)

-Powerful tools for retrieving and manipulating geometry and mesh data (for instance making the mesh more dense)

-Full control over solution stage, allowing for advanced adaptive solution strategies (requires high programing level of an engineer)

-Extended visualization capabilities (possibilities for changing axis names, adding legend, changing line and surfaces colors)

-Advanced numerical postprocessing (for instance calculating mean value of physisic variables or other analysis of the data)[9]

All static and dynamic simulations were carried out in Matlab using proper Comsol functions. In order to fulfill the convergence requirement special scripts has been written that change absolute and relative tolerances in stochastic way. After the convergence of solution for one geometry of a permanent magnets was achieved, the next step was to increment magnets volume. The calculation process is then carried out again until it reaches the final geometry.

Whole calculation process has been depicted in a figure 4.

The problem that was modeled using Comsol (geometry modeling, meshing and PDE problem definition) can be also modeled in Matlab Environment using script language.
4. Results

Selected results of steady and transient states for the simulated processes are presented in this section. Cogging torque has been calculated using time dependent solution with time ranging from 0 to 1/36s with 40 steps. Absolute and relative tolerances were dependent on the selected geometry and, for example for the first geometry, were equal to 0.510 and 0.258, respectively. Complex numbers were not allowed. The solver system that was selected was direct linear solver (UMFPACK) with standard options selected. One iteration of a cogging torque estimation lasted for about 300 s (for high standard computer – Intel I7 – 4-core with 2.8 GHz clock, 4GB RAM, Windows 7 (64-bit) – Dell Vostro 430).
Figure 7. shows comparison of six different structures presented in chapter 2. As it is shown in figures 6., 8. the highest value of cogging torque occurred for the smallest volume of a permanent magnets. The biggest the volume of a permanent magnet, the smaller maximum value of cogging torque, but the proper character of the influence of magnets volume on cogging torque gives fig. 7,8. As it occurred such motor structure should be analyzed more precise in order to get better view of cogging torque changes.

5. Conclusions

The presented model and the proposed method have been successfully implemented in Matlab environment. As it has been shown in the previous chapter, Comsol Multiphysics and Matlab is a very helpful tool for multi physics calculations, particularly in cogging torque and magnetic flux density calculations. The initial geometry can be set in Comsol and CAD programs such as SolidWorks or Autocad. Changing geometry and properties of a model can be done using Comsol or Matlab scripting capabilities. Going further, Matlab can be used for designing and solving optimization problem in geometry of PM and other aspects of magnetic circuits. Of course there is no contraindication to set the initial geometry and material properties in Matlab, but it demands very precise knowledge of the subject.

Cogging torque as a physic phenomenon is very unwanted behavior. It can be minimized by proper volume of a PM.

As it has been shown earlier the cogging torque value for the proposed type of motor decreases according to the increase of the PM volume. It should be emphasized that calculations presented in the paper show a method used on a defined model for calculations of cogging torque and electromagnetic variables, but such aspects as mean value of total torque, magnetic flux saturation, power losses in iron, and other aspects were not considered. In the nearest future it is planned to optimize different geometries of cylindrical PM Synchronous Motors considering many structures and their influence on cogging torque and the mean value of electromagnetic torque.

Bibliography


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