INFLUENCE AND EVALUATION OF NON-IDEAL MANUFACTURING PROCESS ON THE COGGING TORQUE OF A PERMANENT MAGNET EXCITED SYNCHRONOUS MACHINE

Isabel Coenen, Mercedes Herranz Gracia and Kay Hameyer

RWTH Aachen University, Institute of Electrical Machines
Schinkelstraße 4, D-52056 Aachen, Germany, e-mail: Isabel.Coenen@iem.rwth-aachen.de

Abstract – **Permanent magnet excited synchronous machines (PMSM) are finding expanded use as servo-drives due to their high efficiency compared to other drive alternatives. However, they posses a big disadvantage which is the presence of cogging torque. This parasitic effect is additionally influenced by tolerances caused by the fabrication process of the motor. This paper presents the minimisation of cogging torque for a PMSM used as servo-drive considering such manufacturing tolerances.**

I. INTRODUCTION

In permanent magnet excited machines, cogging torque is caused by the interaction between the rotor magnets and the stator slots. It results in undesired effects such as vibration and deformation. Therefore a minimisation of such effects is desired.

There are many approaches to achieve a reduction of cogging torque [1]. All such attempts are usually done for the ideal machine, meaning without considering geometric or material tolerances occurring e.g. during the fabrication process of the machine or its components. However, it can be shown that such tolerances have a strong influence on the cogging torque [2] in particular. Ignoring this influence while minimising, results in a machine design which is susceptible to manufacturing faults.

This paper presents the minimisation of cogging torque for a PMSM considering non-ideal manufacturing process, aiming at a robust design of the machine. Hereby, it is focused on magnetization faults and the use of different qualities of the permanent magnet material. This study is performed employing a stochastic analysis.

II. COGGING TORQUE MINIMISATION

A. Applied methodology

In this study, the approach to minimize the cogging torque is to optimise the machine's geometry. The applied method is a combination of Design of Experiments (DoE) [3] and Finite Element Analysis (FEA).

DoE is used to identify the significance of the influence of various design parameters concerning the cogging torque for the studied machine. For each numerical experiment a FE calculation is performed, where the machine is simulated under no-load condition and the cogging torque is computed by the Maxwell Stress Tensor.

B. Non-ideal manufacturing process

The two considered tolerances of non-ideal manufacturing, which influence the cogging torque and which are known as crucial, are magnetisation faults and a static eccentricity of the rotor.

In case of tolerances in the magnetisation of the permanent magnets, an asymmetrical distribution of the air gap flux-density arises. This results in additional cogging torque. Within this study, it is considered that the magnet's remanence flux-density B_R is varying by ±4%. The amount of additional cogging torque is depending on which and how many magnets are representing a failure. For the studied machine with its eight magnets, 18 configurations can be evaluated being relevant [4].

Static eccentricity means that the centre of the rotor is displaced to a fixed eccentric position. This is crucial because it results in an asymmetrical distribution of the flux-density at the air gap and thereby causes additional cogging torque.

C. Results

The design optimum, achieving minimised cogging torque, is finally determined by the method of gradient descent. In a first step, each of the 18 relevant configurations is minimised separately. To obtain an overall optimum for the machine, the probability of occurrence is calculated for each configuration. Thereby, an average value for the chosen design parameters can be computed, which finally represents the design optimum. For the studied machine, the average of the cogging torque was reduced by 7% when the optimised geometry was applied.

III. STOCHASTIC ANALYSIS

To verify the found design optimum, a stochastic analysis is performed. The remanence flux-density B_R is assumed to be normally distributed [5] by a tolerance width of 4%. Thus, 50 random configurations are created with a random value of B_R for each magnet. The cogging torque is computed for each configuration, with reference as well as with optimised geometry. The results are divided into 16 intervals, where interval I is the one with the lowest and XVI the one with the highest values of cogging torque. Figure 1 illustrates the resulting frequency distribution for both geometries. The distribution for the optimised geometry is shifted to lower intervals compared to the reference one, which shows the achieved reduction of cogging torque. On average the cogging torque is 9% lower when compared to the model with reference geometry.

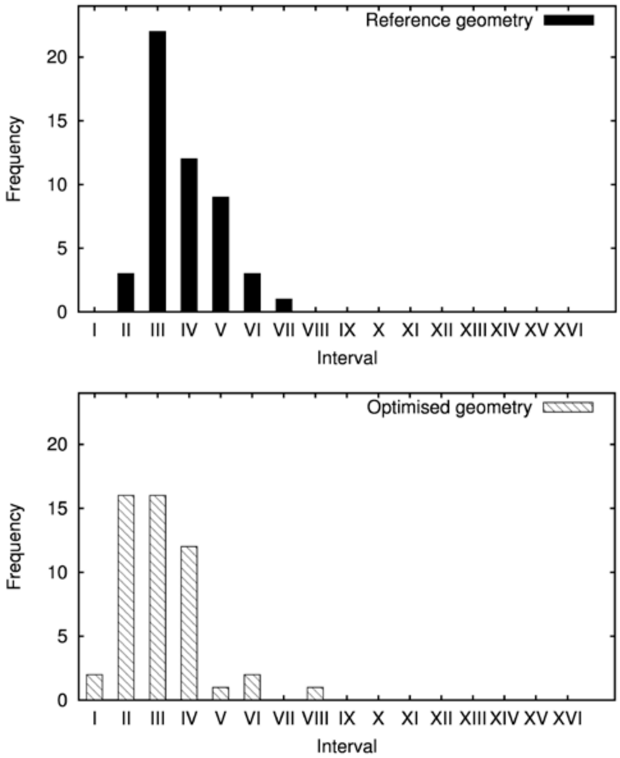

Fig.1. Frequency distribution – normally distributed tolerances.

The quality of the permanent magnets depends on the manufacturing process. A bad quality means that either the tolerance width of B_R or the failure probability is higher. Assuming a uniform distribution for the magnetisation, all failures appear with the same probability. This is inferior to the normal distribution where the density function is a bell-shaped curve.

For the assumed uniform distribution with a tolerance width of 4% the same procedure as described for the normal distribution is performed. Figure 2 shows the resulting frequency distribution for reference and optimised geometry of the model. The intervals are identical to those in figure 1. The average reduction of cogging torque, by applying the optimised geometry, is also 9%. Compared to the results of the normal distributed tolerances, the variance of distribution and the average values of cogging torque are higher.

Finally, the results of this stochastic analysis prove that the optimised geometry is robust against manufacturing faults. The influence of varying qualities of the magnets is shown by modelling the tolerances using different probability distributions.

In general, it can be stated that a better quality of the magnets requires a higher precision during manufacturing, which may result in higher material costs. This study provides an approach to prove the use of a bad quality for a possible reduction of the fabrication costs.

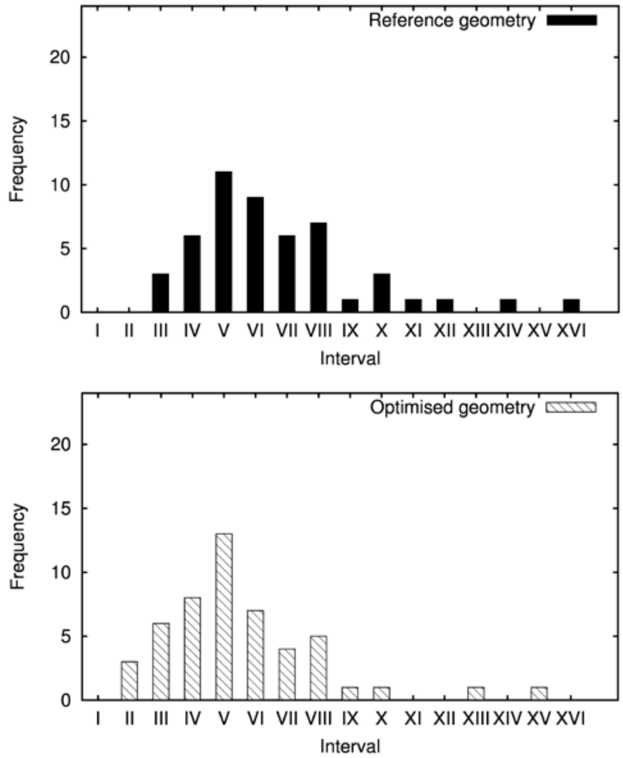

Fig.2. Frequency distribution – uniformly distributed tolerances.

IV. CONCLUSIONS

This paper shows the minimisation of cogging torque of a PMSM with respect to manufacturing tolerances and failures. A robust design of the machine is achieved by using numerical simulations combined with statistical methods such as Design of Experiments. A stochastic FEA is performed to validate this design and to investigate the influence of different qualities of the permanent magnets.

The details of the minimisation and further investigations on the magnet quality will be presented in the full paper.

REFERENCES

[1] M.S. Islam, S. Mir, T. Sebastian "Issues in reducing the cogging torque of mass-produced permanent magnet brushless DC motor", *Conference Record of the Industry Applications Conference, 38th Annual Meeting*, vol.1, pp. 393-400, 2003.

[2] L. Gasparin, A. Cernigoj, S. Markic, R. Fiser, "Additional Cogging Torque Components in Permanent-Magnet Motors Due to Manufacturing Imperfections", *IEEE Transactions on Magnetics*, vol. 45, No. 3, pp. 1210-1213, 2009.

[3] D. C. Montgomery, "Design and analysis of experiments", *John Wiley & Sons*, New York, 1976.

[4] C. Schlensok, M. Kurzidem, K. Hameyer, "Novel method for fast analysis of cogging-torque harmonics in permanent-magnet synchronous-machines ", *IEEE Conference on Electromagnetic Field Computation*, CEFC 2006, Miami, pp. 330–330, 2006.

[5] Y. Kim, J. Hong, J. Hur, "Torque Characteristic analysis Considering the Manufacturing Tolerance for Electric Machine by Stochastic Response Surface Method", *IEEE Transaction On Industry Applications*, vol. 39, No. 3, pp. 713-719, 2003.

[6] M. Herranz Garcia, "Methoden zum Entwurf von robusten Stellantrieben unter Berücksichtigung fertigungsbedingter Abweichungen", Ph.D. thesis, IEM, RWTH Aachen University, 2008.