Comparison of numerical methods for the prediction of cogging torque in 2D and 3D

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***Abstract*: A reliable numerical estimation of the cogging torque is a basic prerequisite before its reduction can be studied. The influence of the model discretization and the calculation method on the cogging torque calculated with a 2D simulation has been already investigated in previous works. This paper extends this investigations to the prediction of cogging torque in machines without axial uniformity, such as magnet skewing or stepping. This lack of uniformity can be considered either by a 2D multi-slice simulation or by a 3D simulation. These both approaches are compared referring their robustness with respect to the calculation methods (Maxwell Stress Tensor, Arkkio and FEMA) and the mesh discretization.**

***Keywords*: force calculation, cogging torque**

I. Introduction

Permanent-magnet synchronous machines (PMSM) are easier to control and more efficient than induction machines. However, they have an undesired cogging torque, due to the interaction of the rotor magnets and the stator slotting. Its reduction is commonly a design objective. Therefore, a reliable estimation of the cogging torque is necessary.

Although analytical methods have been used in the past, the prediction of the cogging torque as a post-processing step of a two-dimensional numerical simulation has become state of the art. Some previous works have shown that the results depend strongly on the model discretization and on the calculation method [1].

The prediction of the cogging torque of a PMSM with a skewed or stepped rotor implies the consideration of a non-uniform magnetic behavior in the axial direction. This can be solved either with the multi-slice method, using 2D simulations [2], or with a 3D simulation. The objective of this paper is the comparison of these two approaches and the study of the sensibility of each of them with respect to the mesh discretization and the calculation methods. The study is carried out on a PMSM with $p = 4$ pole pairs and $N_1 = 18$ stator slots, whose rotor is stepped in two parts with a stepping angle $\alpha_{step} = 2.5°$.

II. Considered models and calculation methods

The FE models are meshed with triangles for 2D and tetrahedra for 3D. The airgap is meshed using three element layers. Four 2D meshes, with number of elements between 57,856 and 415,196, and three 3D meshes, with number of elements between 502,807 and 1,816,087 have been compared.

Three force calculation methods have been compared: Maxwell Stress Tensor (MST), Arkkio [3] and an analytical approximation of the magnetic potential in the air-gap using the values of the numerical simulation as boundary conditions (FEMA) [4]. The latter is only used for 2D.

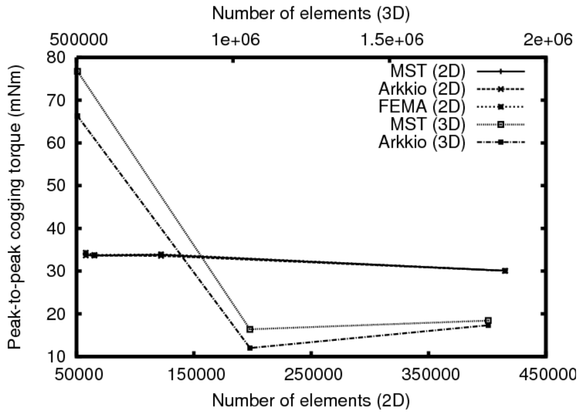

Figure 1. Cogging torque for the different meshes and methods

III. Results

The results of the cogging torque from the 2D and the 3D simulation are first compared without taking the stepping of the rotor into account. Fig 1 shows the dependence of the peak-to-peak value of the cogging torque with the calculation method and the mesh.

In 2D, all calculation methods converge to the same result for the finer mesh. If this result is, therefore, assumed as correct, the discretization error for the rougher mesh is up to 10% of the cogging torque. Otherwise, the influence of the calculation method in 2D is smaller and inversely proportional to the number of elements. For the rougher mesh, the three methods show differences up to 2%. Arkkio delivers for the rougher meshes the most similar values to the ones of the very fine mesh.

The influence of the discretization as well as the calculation method is much bigger in 3D as in 2D. Even the results of the finer mesh with nearly two millions elements differ up to 6%. This means, that the same precision as in 2D cannot be achieved.

The results of the finer meshes in 2D and 3D show up a difference of 10 mNm due to the lower precision of the 3D calculation and the neglection of end effects in 2D.

Further results and details about the calculation methods will be presented in the full paper.

References

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