Model of an ironless axial flux permanent magnet motor based on the field produced by a single magnet

Maxime Bonnet, Yvan Lefèvre, Jean-François Llibre, François Defaÿ

Model of an Ironless Axial Flux Permanent Magnet Motor Based on the Field Produced by a Single Magnet

Maxime Bonnet[1], Yvan Lefèvre[1], Jean-François Llibre[1], and François Defay[2]

[1] LAPLACE, Université de Toulouse, CNRS, INPT, UPS, France
[2] ISAE-SUPAERO, Université de Toulouse, Toulouse, France

***Abstract*—The Lorentz force law is proposed as an alternative to the Maxwell stress tensor to calculate the torque of an ironless AFPM motor. This alternative allows calculating only the magnetic field produced by magnets. A model of this field based on the field produced by one magnet, the superposition principle and geometric transformations is proposed. The method is validated by full 3D FEA simulations and experimental measurements performed on a test bench.**

***Index Terms*—Axial Flux Permanent Magnet, Ironless, Torque, Bio-Savart's law, Lorentz force law**

I. Introduction

Applications such as aeronautics are seeking to use ironless-stator Axial Flux Permanent Magnet (AFPM) motor [1]. Thanks to new manufacturing processes such as 3D printing it is possible to open new markets for AFPM motors [2].

Usually the Maxwell stress tensor method is used to compute the torque produced by an electric motor. The use of this method requires computing the total magnetic field produced by all the sources. For ironless AFPM motor with sources, permanent magnets and windings, having axial symmetry, integral formulations based on Bio-Savart's law and the superposition principle are applied in [3] to calculate the total magnetic field.

In some cases, the Lorentz force law method may be an alternative to the Maxwell stress tensor method to compute forces and torques. In the case of ironless AFPM motor, the use of Lorentz law requires only the magnetic field produced by magnets. This is very useful when the geometry of the coils is very complex with no straightforward symmetry, as in [4] where a 3D Finite Element Analysis (FEA) is used to compute the magnetic field produced by magnets. The purpose of this article is to replace the 3D FEA by an appropriate model.

II. Magnetic Field Produced by Magnets

To calculate the magnetic field produced by magnets, a reference magnet must be selected. The field produced by this magnet in the windings is calculated by integral formulations based on Bio-Savart's law [5]. To calculate the field of each magnet from the field produced by the reference magnet, geometric transformations based on symmetry considerations are used. The field produced by all magnets on this point is get by superposition principles.

In the final paper, the geometric transformations, required to calculate the field of each magnet from the field of the reference magnet, will be established by using symmetry considerations and the relative positions of each magnet to the reference magnet.

III. Simulations and Experimental Results

A prototype of an ironless AFPM has been manufactured. This prototype has two air gaps because it is composed of two rotors and a single stator. Each rotor has 8 cylindrical magnets. The coils are trapezoidal in shape [4]. The magnetic field produced by the magnets in coils has been calculated by the proposed method. The torque is calculated by the Lorentz force law taking into account the complex windings geometries. To validate the method, the torque for given supply currents is calculated for each rotor position and is compared to the torque obtained from full 3D FEA and the torque measured on a test bench (Fig. 1).

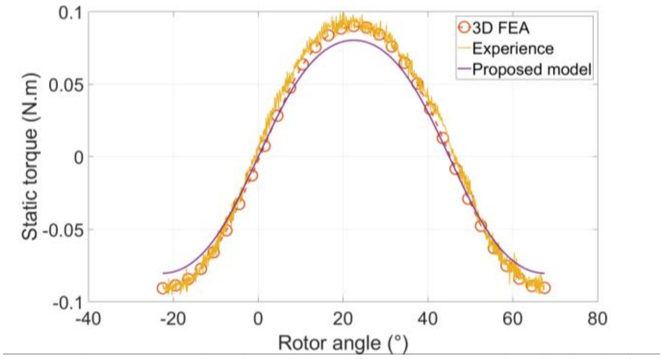

Fig. 1. Static torque as a function of the rotor angle over an electrical period.

IV. Conclusion

This proposed model can be adapted to the components of an ironless AFPM motor: permanent magnets geometries, windings geometries, number of air gaps and number of poles.

References

[1] Z. Zhang, W. Geng, Y. Liu and C. Wang., "Feasibility of a new ironless-stator axial flux permanent magnet machine for aircraft electric propulsion application," China Electrochemical Society (CES) Transactions on Electrical Machines and Systems., vol. 3, no. 1, 2019.

[2] A. Kampker, P. Treichel, K. Kreisköther, R. Pandey, M. Kleine Büning and T. Backes, "Alternative fabrication strategies for the production of axial flux permanent magnet synchronous motors for enhanced performance characteristics," IEEE, 8th International Electric Drives Production Conference (EDPC), 2018.

[3] R. M. Wojciechowski, "Analysis and optimisation of an axial flux permanent magnet coreless motor based on the field model using the superposition principle and genetic algorithm", Archives of Electrical Engineering, 2016, vol. 65(3). pp. 601-611.

[4] M. Bonnet, Y. Lefèvre, J.F. Llibre, D. Harribey, F. Defay and N. Sadowski, "3D Magnetic Field Model of a Permanent Magnet Ironless Axial Flux Motor with Additively Manufactured Non-Active Parts," 19th International Symposium on Electromagnetic Fields in Mechatronics (ISEF), Nancy France, Aug. 2019

[5] E. Durand, Magnétostatique, Masson et Cie, Paris, 1968