Relative permeability in a 3D analytical surface charge model of permanent magnets

Published in:
15th Biennial IEEE Conference on Electromagnetic Field Computation (CEFC 2012), 11 Nov - 14 Nov 2012, Oita, Japan

Published: 01/01/2012

Document Version
Accepted manuscript including changes made at the peer-review stage

Please check the document version of this publication:

• A submitted manuscript is the author's version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
• The final author version and the galley proof are versions of the publication after peer review.
• The final published version features the final layout of the paper including the volume, issue and page numbers.

Link to publication

Citation for published version (APA):

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

• Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
• You may not further distribute the material or use it for any profit-making activity or commercial gain
• You may freely distribute the URL identifying the publication in the public portal?

Take down policy
If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Download date: 18. Dec. 2018
Relative Permeability in a 3D Analytical Surface Charge Model of Permanent Magnets

Maarten F. J. Kremers, Johannes J. H. Paulides, Esin Ilhan, Jeroen L. G. Janssen and Elena A. Lomonova
Electromechanics and Power Electronics Group, Eindhoven University of Technology
Eindhoven, 5612AZ, The Netherlands
Email: m.f.j.kremers@tue.nl

Abstract—Analytical methods for the calculation of the magnetic field such as the surface charge method offer high accuracy at a reduced calculation time compared to the Finite Element Method. However, for the surface charge model the relative permeability of the permanent magnets is assumed to be equal to air, \( \mu_r = 1 \), thus an error is made in the calculation of the magnetic field strength of the magnet. In this paper the relative permeability of the magnet is taken into account in order to obtain an exact solution for the magnetic field. The interaction force between two magnets is calculated using the newly obtained expressions for the magnetic field.

I. INTRODUCTION

Many devices operate on the interaction force exerted between two magnets. Some examples are magnetic bearings, magnetic couplings, and magnetic vibration isolation. Vibration isolation is a critical factor for enabling micro-lithographic machines to produce integrated circuits at high throughput speed with small details. For the vibration isolation system a permanent magnet based system is considered. This system needs to be modeled with very high accuracy in order to obtain a system with good performance.

Analytical models offer high accuracy at a reduced calculation time with respect to the 3D FEM. However, the models constructed with the analytic surface charge method \([1]\) do not take the relative permeability of the magnets into account which affects the accuracy of the model \([2]\).

II. INCLUSION OF RELATIVE PERMEABILITY OF THE MAGNET

The assumption that \( \mu_r = 1 \) in the surface charge method leads to a simplified expression for the magnetic field. However, this assumption introduces a modeling error. In order to calculate an accurate solution of the magnetic field, relative permeability has to be taken into account. By adjusting the surface charge distribution, the equivalent charge \([3]\) for the magnet is obtained. The magnetic material with a relative permeability of \( \mu_r \) and a magnetic remanence of \( B_{rm} \) is replaced with an induced surface magnetic charge density \( \sigma_{m1} \) and \( \sigma_{m2} \) on both sides of the boundary of the magnet.

In order to compare the difference in accuracy of the surface charge model with a relative permeability of \( \mu_r = 1 \) and the surface charge model with \( \mu_r = 1.03 \), two FEM models are constructed. Both FEM models have the same geometry and magnetization, but different permeability of the magnetic material. Model FEM-\( r1 \) has a relative permeability of \( \mu_r = 1 \) for the magnetic material, while model FEM-\( r103 \) has a relative permeability of \( \mu_r = 1.03 \). The analytically obtained solutions and FEM results are plotted along a line over the magnet, shown in Figure 1. This line has a length of 1.5 times the length of the magnet and is centered at the origin on a height of 0.5 mm above the surface of the magnet.

The maximum difference between the surface charge model with a relative permeability of \( \mu_r = 1.03 \) and FEM-\( r103 \) is smaller than 1 mT instead of 10 mT difference for the surface charge model with \( \mu_r = 1 \) for the magnet, which demonstrates the excellent capabilities of this enhanced surface charge model.

III. EXPERIMENTAL VERIFICATION

To validate the performance of the analytic model which accounts for the relative permeability of the magnet described above, the force interacting between the two magnets is calculated and the results are validated with two FEM models and measurements.

REFERENCES