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

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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 \( \mu_{r_1} \) and a magnetic remanence of \( B_{r_{rm_1}} \) is replaced with an induced surface magnetic charge density \( \sigma_{m_1} \) and \( \sigma_{m_2} \) on both sides of the boundary of the magnet.

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, where 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+103 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