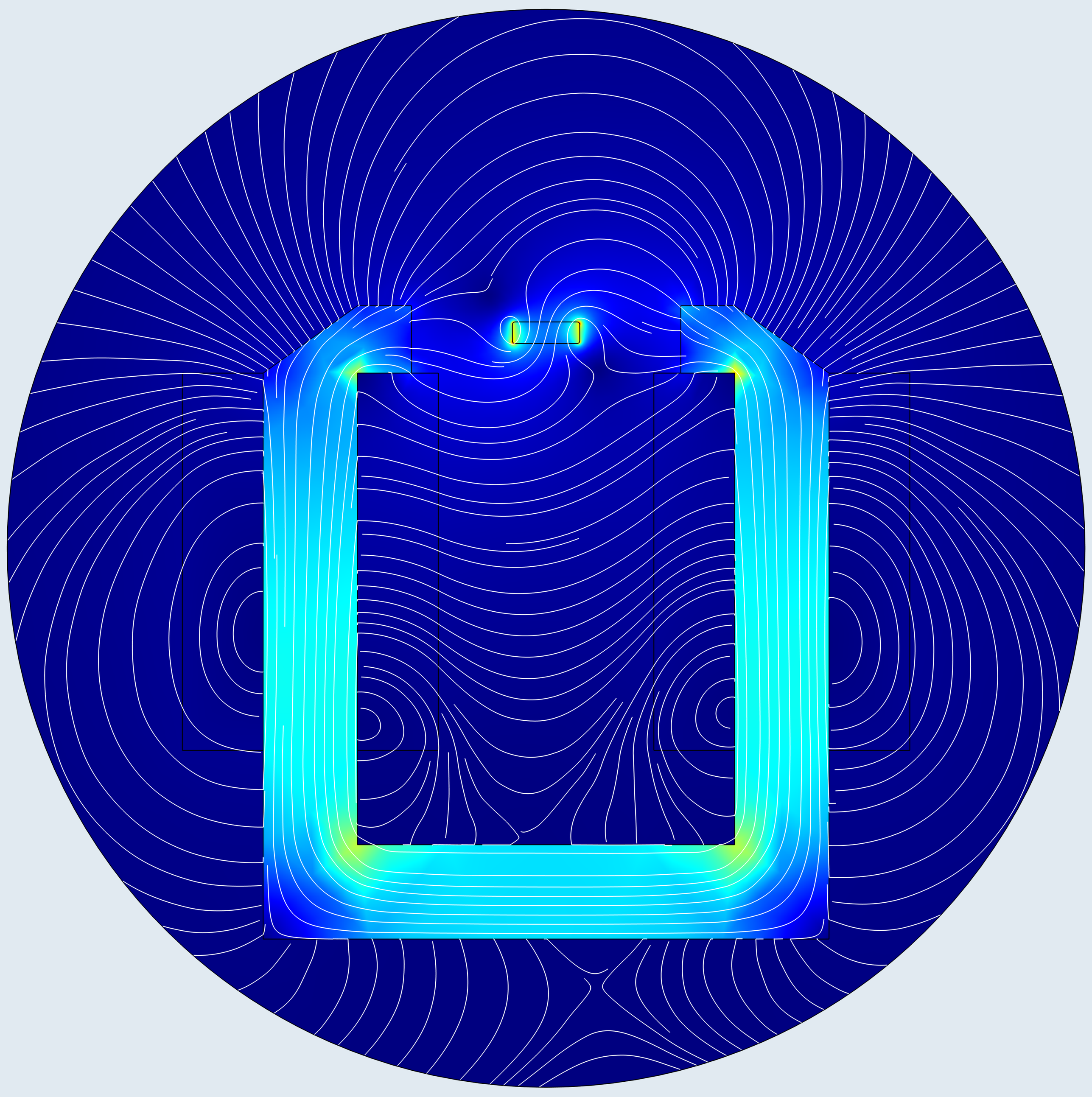

Modeling of a Hybrid-Integrated Moving Magnet Drive for a Quasi-Static 2D-MEMS Vector Scanner

A finite element and analytical model of a moving magnet-based MEMS drive to facilitate design explorations and control system development.

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Introduction

Quasi-static 2D-MEMS vector scanners are micro-opto-electro-mechanical systems (MOEMS) made of monocrystalline silicon. The primary application for these controllable micromirrors is the high dynamic and precise deflection of laser beams, for example in light detection and ranging (LiDAR) or optical coherence tomography (OCT) systems. Despite the challenges associated with system integration, hybrid-integrated electromagnetic (EM) drives, specifically moving magnet drives, offer very high energy densities and fast response times. Additionally, they can achieve large deflections at low driving voltages, thereby enabling innovative MOEMS designs and applications. However, for rapid exploration and simulation of new design variants, as well as for the development of control algorithms, numerical and analytical modeling of an EM drive is indispensable.

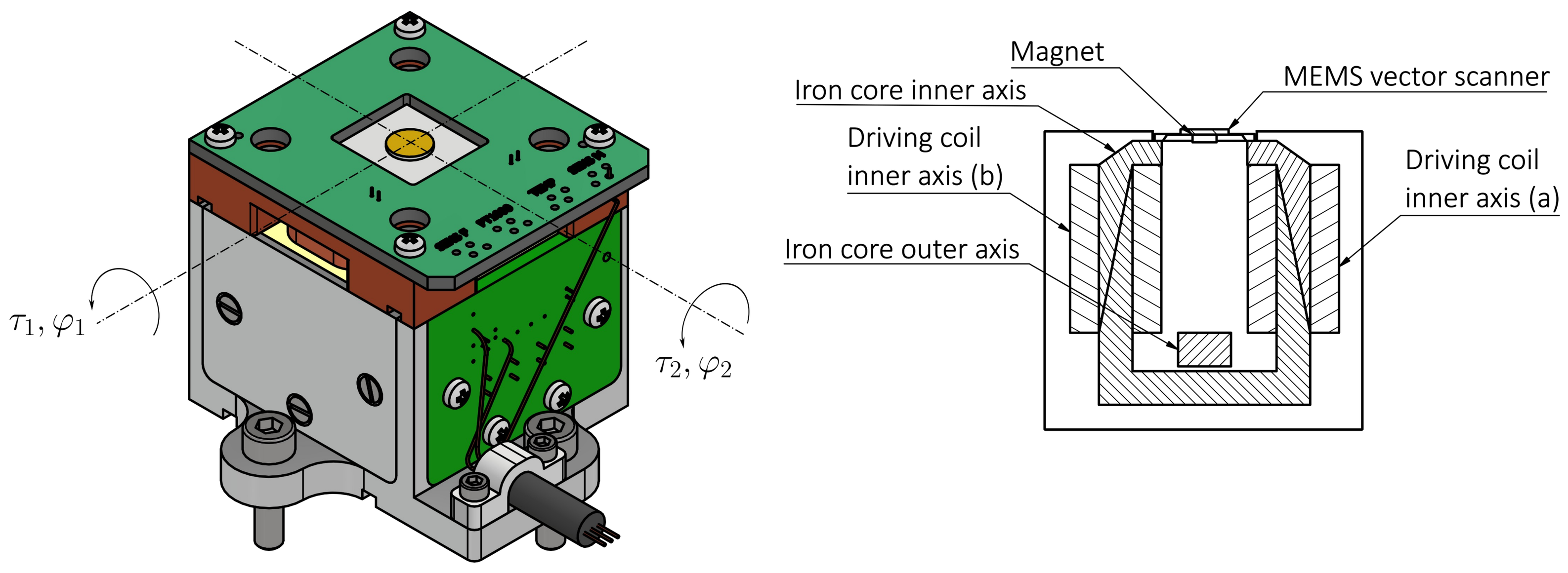

FIGURE 1. Left: Quasi-static 2D-MEMS vector scanner with EM driving system and enclosure. Right: Section view.

Methodology

In this work, a 2D finite element (FE) model of a moving magnet drive is presented using COMSOL®'s AC/DC Module for a magnetostatic analysis. The analytical model is based on the magnetostatic Maxwell's equations $\nabla\times\boldsymbol{H} = \boldsymbol{J}$, $\nabla\cdot\boldsymbol{B} = 0$ for $\boldsymbol{J} = 0$. Introducing the magnetic scalar potential $\boldsymbol{H} = -\nabla\Phi_m$ and constitutive relation $\boldsymbol{B} = \mu_0(\boldsymbol{H}+\boldsymbol{M})$ results in the Poisson equation $\nabla^2\Phi_m = \nabla\cdot\boldsymbol{M}$, which can be solved i.e. using Green's function (Ref. 2). It is then shown in Ref. 1 that the torque on a permanent magnet in an external magnetic field $\boldsymbol{B}_{ext}$ is

$$\boldsymbol{\tau} = \int_v \rho_m(\boldsymbol{r}\times\boldsymbol{B}_{ext})\,dv + \oint_s \sigma_m(\boldsymbol{r}\times\boldsymbol{B}_{ext})\,ds$$

where ρ_m and σ_m are the volume and surface charge density, resp.

Results

The torque on a NdFeB permanent magnet within the magnetic field generated by the proposed EM drive (Fig. 1) is calculated in COMSOL for a set of predefined deflection angles, and the results are compared to the analytical model (Fig. 2). The external magnetic field $\boldsymbol{B}_{ext}$ of the analytical model is determined using a reluctance network, as described in Ref. 3. The results of the numerical simulation show strong agreement with the analytical model. The deviation of the analytically calculated value of $\boldsymbol{B}_{ext}$ from the FEM results in the magnet region is $< 4\%$, while the deviation of the calculated torque in the relevant deflection range is $< 7\%$. This difference is primarily due to the reluctance torque, arising from the attractive force between the magnet and the iron core, which is not included in the analytical model.

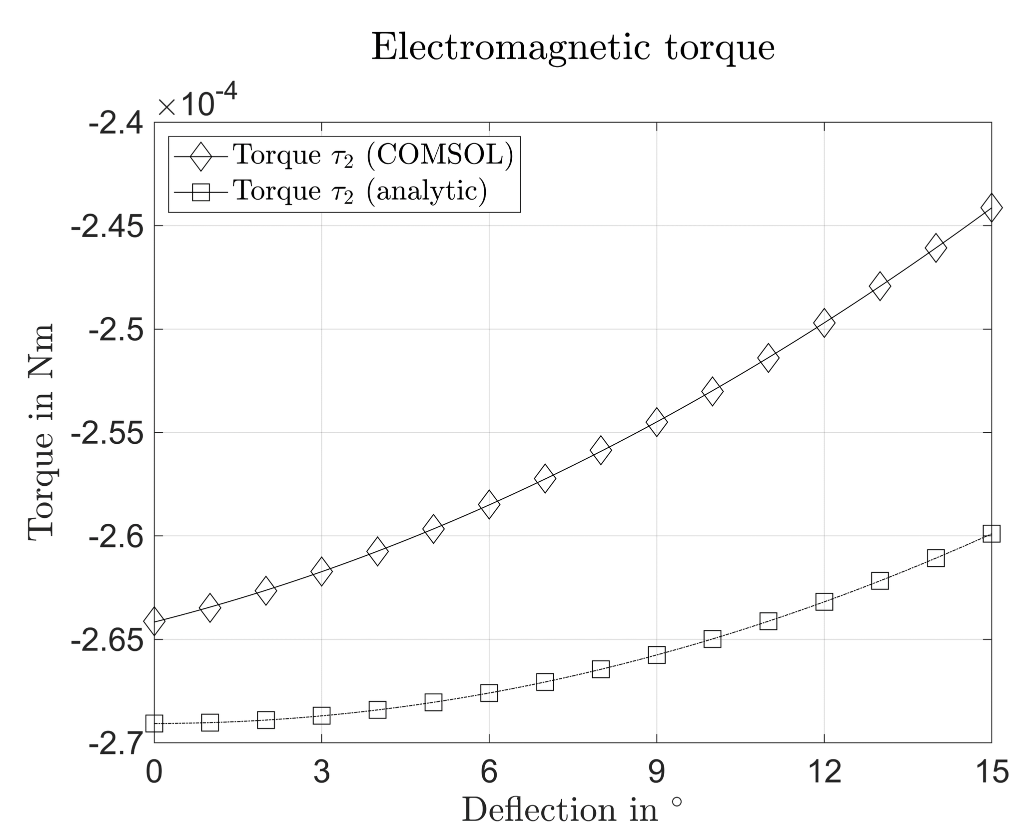

FIGURE 2. Electromagnetic torque τ_2 calculated analytically and using COMSOL®, exemplarily shown for the deflection φ_2 (inner axis) and a driving current of $i_{drv} = 1\text{A}$.

REFERENCES

1. E. P. Furlani. Permanent Magnet and Electromechanical Devices – Materials, Analysis, and Applications. Academic Press, 2001.
2. J. D. Jackson. Classical Electrodynamics. 3rd Edition, Wiley & Sons, Inc. New York, 1998.
3. D. Hanselman. Brushless Permanent Magnet Motor Design. Magna Physics Publishing, 2006.

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