DOI 10.5162/SMSI2023/P28

Ring Magnet Optimization for Magnetic Angle Measurement

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Summary:
We present an optimization method for diametrically magnetized ring magnets, which are often used in magnetic angle measurement applications. For such magnet geometries, fast analytical models fail due to the strong material feedback. To address the latter, the Magnetostatic Method of Moments is implemented based on recently found analytical solutions for cylindrical rings and ring segments. The implementation is efficient enough to allow geometry optimization using standard methods.

Keywords: magnet optimization, method of moments, analytical field calculation, cylinder ring/segment/tile, magnetic angle measurement

Background and Motivation

Magnetic angle sensor systems are often realized with ring magnets with diametrical magnetization. The sensor is located inside the rotating ring (see Fig. 1), where the magnetic field is very homogeneous, so that the sensor system is quite robust against mechanical sensor displacements [1].

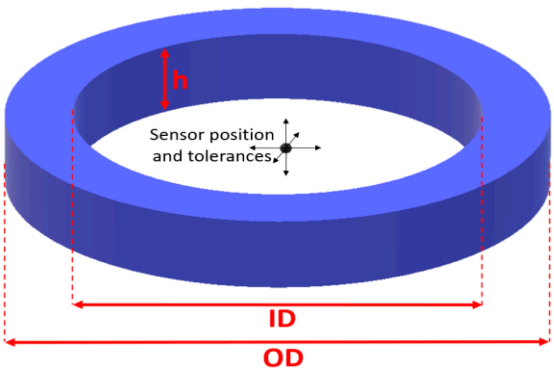

Fig. 1. Sketch of the cylinder ring with the geometrical parameters and the sensor in its center.

Recent work has shown that the Magnetostatic Method of Moments (MoM) can be used to simulate material interactions of magnetic bodies [2]. This method is particularly efficient when the region of interest is outside the magnetic material itself, which means that only a few cells are required, and when the calculation of the interaction is computationally efficient.

The open-source Python package Magpylib provides a fast and numerically stable calculation of the magnetic field of uniformly magnetized geometries based on analytical expressions from the literature [3]. The latest version 4.1.2 also includes the recently published full analytical solution for cylindrical ring segment geometries [4].

In the following, we show that it is possible to combine the analytical calculations of Magpylib with the MoM to calculate the behavior of materials in cylindrical geometries. The efficiency of the computation allows to solve system layout optimization problems with complex cost functions that are difficult to treat otherwise. With numerical methods, like finite element, it is practically impossible to solve global optimization problems in higher dimensions.

Computation Method

Our implementation of the MoM is based on point matching, which means that the cell interaction is approximated by the field at the barycenter. We choose a discretization of the cylindrical ring into ~50 elements (see Fig. 2) and a linear material response described by the susceptibility χ.

Optimization Problem

The cost function to be minimized considers the sensor displacement and the minimum field amplitude. We assume a possible mechanical tolerance of ±1 mm in the sensor position (in radial and axial directions) and want to accept a maximum angular error of 0.1° (based on a 2D field measurement, see [1]) and a minimum field amplitude of 25mT over the entire 360° rotation, regardless of the tolerances (see Fig. 1). To guarantee enough space for the sensor, we further assume ID≥10mm. With these constraints, we aim to minimize the magnetic material. It is assumed to have a magnetic remanence polarization of 500mT, a common value for bonded magnets.

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Varying the inner and outer diameters ID, OD, and the height h of the cylindrical ring in Fig. 1 leads to an optimization problem in three dimensions. The objective function to be minimized is the volume of the cylindrical ring. The bounds for the angular error and the field amplitude can be included via penalty terms. This optimization can be performed with several different algorithms, e.g. differential evolution in scipy.optimize [5].

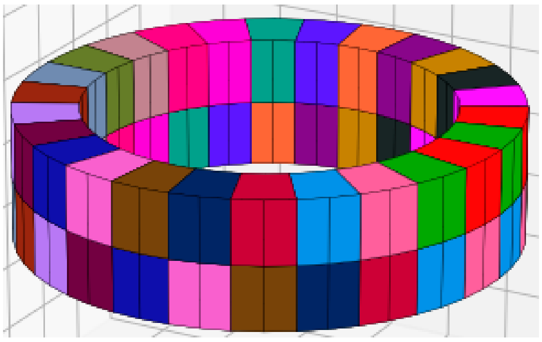

Fig. 2. Sketch of the discretized cylinder ring with ~50 cylinder cell elements. The demagnetization effect can be calculated via the interaction between the individual cells.

Results

In Fig. 3 we show that the method we use leads to a reasonable accuracy compared to the simulation with the finite element method in ANSYS for a cylindrical ring with χ=0.2 (OD=19mm, ID=14mm, h=10mm). We note that near the center we can achieve relative errors below 3% even with very few cells (see Fig. 3).

We solve the described optimization problem with three different assumptions: perfect hard magnetic material with χ=0, high quality neodymium magnets with χ=0.05 and bonded magnets with χ≥0.2. The found optimum values for different permeabilities are shown in Tab. 1.

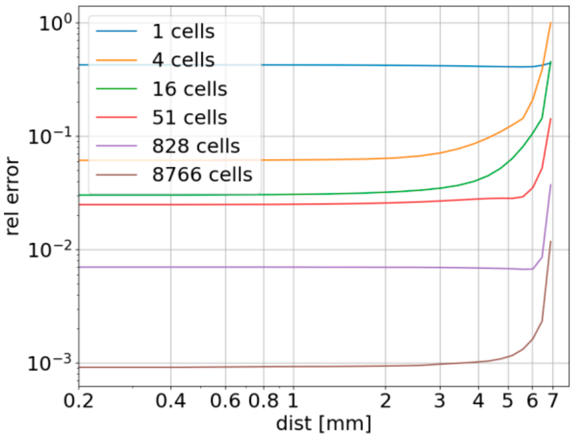

Fig. 3. Error of MoM and point matching with the analytical solution, compared with a finite element method. The maximum relative amplitude error of the field at different distances from the center is given for different numbers of cells.

Tab. 1: Results of the optimization

χ	ID [mm]	OD [mm]	h [mm]	V [mm³]
0	10.00	13.56	12.95	851.69
0.05	10.00	14.00	13.00	981.72
0.2	10.00	15.48	13.26	1454.94
0.5	10.00	18.41	13.84	2596.81

Conclusion

Using the example of angle measurement with cylindrical ring magnets, we have shown how the Magnetostatic Method of Moments can be used in combination with the analytical solution of cylindrical tiles for solving optimization problems including material response.

We have demonstrated that different susceptibility values result in different geometric optima. It is interesting to observe how strongly the required magnet volume increases with the susceptibility.

In conclusion, we have presented a good example, where optimization without consideration of material response leads to results far from the actual optimum.

References

[1] Y. Y. Lee, R.-H. Wu, S.T. Xu, Applications of Linear Hall-Effect Sensors on Angular Measurement, *2011 IEEE International Conference on Control Applications (CCA),* pp. 479-482 (2011); doi: 10.1109/CCA.2011.6044465

[2] O. Chadebec, J.-L. Coulomb, F. Janet. A review of magnetostatic moment method, *IEEE Transactions on magnetics*, 42(4):515–520 (2006); doi: 10.1109/TMAG.2006.870929

[3] M. Ortner, L. G. C. Bandeira. Magpylib: A free python package for magnetic field computation. *SoftwareX,* 11:100466, 1 (2020); doi: 10.1016/j.softx.2020.100466

[4] F. Slanovc, M. Ortner, M. Moridi, C. Abert, D. Suess. Full analytical solution for the magnetic field of uniformly magnetized cylinder tiles, *Journal of Magnetism and Magnetic Materials,* 559:169482, 10 (2022); doi: 10.1016/j.jmmm.2022.169482

[5] R. Storn, K. Price. Differential evolution – a simple and efficient heuristic for global optimization over continuous spaces. *Journal of Global Optimization,* 11:341–359 (1997); doi: 10.1023/A:1008202821328