3D printing of magnetic filament for shimming permanent magnets

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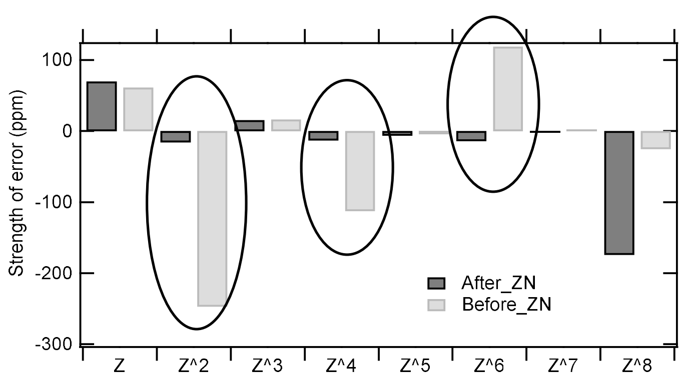
Introduction: Previously, we have successfully implemented magnetic ink to passively shim relatively high quality magnets.[1] However, the ink is not magnetically strong enough to shim simpler, cheaper magnets. We have found that 3D printing of magnetizable filament can achieve the required strong correction. For iron-core dipole magnets, the method can be effective in addressing the inhomogeneities that result from the finite pole diameter. For cylindrical Halbach arrays, the stronger corrections may all that is needed to address the inhomogeneities due to material property variations and the impact of the finite magnet length. For both types of magnets, more compact designs and simpler assembly processes may be enabled.

Methods: We use a commercially available PLA (polylactic acid) filament containing iron powder and a popular mid-level consumer-style 3D printer. The ease of printing shims allows us to address most questions experimentally, using NMR-based field mapping.

Results and discussion: We have found that the filament has an appropriately strong magnetization density and polarizes reproducibly in magnetic fields well below its saturation field. The commercially available 3D printer has sufficient resolution and precision. The printed filament material is both isotropic and linear, and the finite volume of the material, which leads to a build-up of thickness in the shim, can be accounted for via calibration.

The shim design for a particular magnet may be based on measured field maps for iron-pole magnets or on calculated fields for Halbach arrays. The design can be found using simple least squares minimization, linear programming, SVD-based techniques, or other methods.

The main limit for the method is in the software that slices the calculated shim design into layers for 3D printing. The printer operates from a text file containing g-code, and we find it useful to produce this g-code ourselves in order to achieve higher resolution in the rendering of the mathematical shim design. We have produced corrections in the form $\pm Z^{2N}$ for N= 1,2, and 3 for a 0.3T iron-pole magnet. The impact of these shims on measured field errors of the form Z^n is shown in Figure 1. These shims are constructed from annular-shaped elements. To correct other field errors, the annular elements were divided in arc segments with independent heights. For Halbach ring magnets, the shims consisted of 64 rectangular tiles of independent height arrayed on the surface of a cylinder. Shims for magnets of field 0.3, 0.5, and 1.4 T have been implemented.



Conclusion: 3D printing of magnetic filament is an effective approach for shimming magnets that require strong correction fields.

References: [1] McDowell & Lown, App. Magn. Reson. (2023).

Figure 1. The mitigation of Z^{2N} errors (see ovals) in a 0.3 T iron-core dipole