A New Approach for Shimming Halbach Ring Magnets: Magnetically Soft Materials

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Introduction: The Halbach Ring Magnet design is attractive due to its mathematical sophistication, compact size, and expected high homogeneity. Also, significant resources exist to aid those wishing to build their own [1]. However, the homogeneity achieved is often less than hoped for and may undermine applications requiring better field quality. We have adapted our methods for using magnetically soft materials for passive shimming [2] to the Halbach Ring Magnet geometry. Magnetically soft materials are more precise and accurate than hard materials and are generally easier to manipulate. By using these passive materials, we seek to achieve field improvements previously requiring thorough material characterization and careful mechanical adjustment of permanent magnet blocks.

Methods: Magnetically soft materials become magnetized in the direction of B_0 once placed in the magnet. Hence, the use of soft materials for the ring magnet configuration requires a rethinking of the geometrical properties of the shim fields. Following a method inspired by the work of Anderson [3], we show that the unipolar material can produce the familiar harmonic fields of either sign. We demonstrate that a compact shim structure defined by a small number (64) of localized regions of constant magnetic moment density is capable of producing harmonic fields through the fourth order, or more.

Results and discussion: We have used 3D printed shims to correct a lab-made 0.3T Mandhalas-style magnet and a 0.5T ring magnet built from arc-segments. We have also applied both 3D printing and 2D magnetic ink printing to correct a much more homogeneous 1.4T magnet. Figure 1 shows two examples in the form of before/after field maps.

Commercially available soft magnetic materials such as ink for jet printing or filament for 3D printing are consistent enough to allow for shimming to succeed. In addition, the available printers and software are well-suited to rapid, nearly automatic production of inexpensive shims. The lack of steel in a Halbach Ring Magnet allows theoretically simple calculation of the expected shim fields with adequate accuracy for developing useful shim designs.

Conclusion: The ability to use well-engineered consumer printers (both 3D and 2D) for shim production removes practical barriers for considering complex designs. We show that the magnetic ink and filament materials, together with their printing processes, are accurate enough to realize the calculated design at a useful precision. We discuss the remaining limitations for achieving very high homogeneity, including the lack of magnetic strength in the ink shims and the need to develop custom software for controlling the 3D printer. Magnetically soft materials provide an effective and efficient path to higher homogeneity Halbach Ring Magnets.

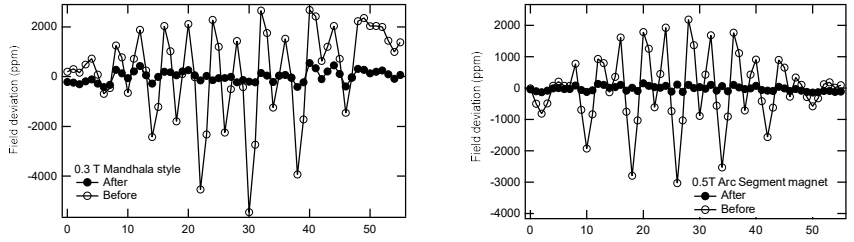

Fig. 1: Before/After 10mm spherical field maps of two Halbach Ring Magnets.

References:
[1] Blümler, Conc. Mag. Reson. (2004).
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[3] Anderson, Rev. Sci. Inst. (1961).