Using Multiple Cylindrical Halbach Rings in Magnetic Particle Imaging

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INTRODUCTION

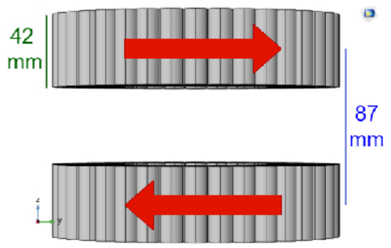
Magnetic Particle Imaging (MPI) is a medical imaging method that quantitatively measures the spatial distribution of a tracer based on magnetic nanoparticles [1,2]. In MPI, a selection field containing a field-free point (FFP) or a field-free line (FFL) is used to enable spatial selection of a particular region so to achieve spatial coding [3]. Using FFL, instead of FFP, reduces acquisition time, improves sensitivity, and signal-to-noise ratio (SNR) [4]. In this study, FFL was formed by using multiple Halbach rings that generated a homogenous dipole magnetic field. A magnet system was designed using three-layer Halbach rings and their effects on FFL performance for each layer were investigated.

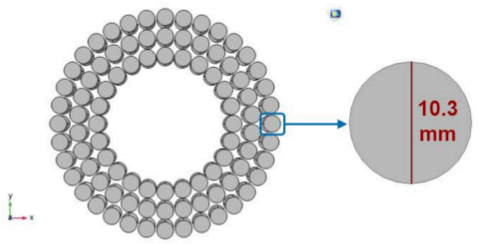
AIM

This study is based on the design of a Halbach magnet system for the selection field in MPI. The main goal of this investigation is to improve the selection field. Therefore, improvement in the selection field was demonstrated by using multiple (nested) Halbach rings.

METHOD

In this study, FFL was generated using two dipole Halbach rings, such that the magnetization direction of one ring is rotated by 180 degree with respect to the other ring. Each ring consist of n cylindrical permanent magnets. Simulated magnetic flux density and gradient field strength for each layer in this design were obtained using COMSOL Multiphysics® software.

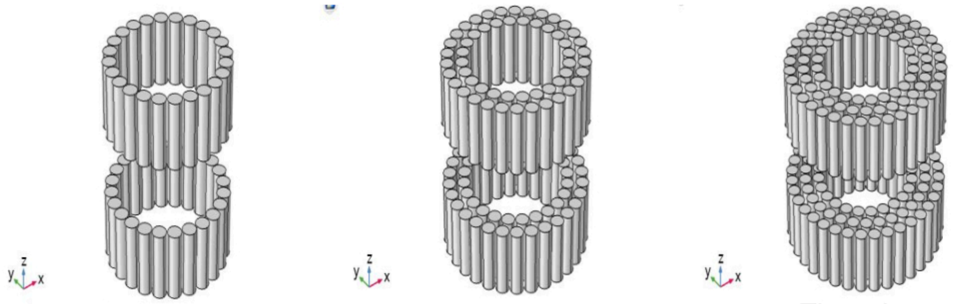




Design Dimensions:

- The innermost layer, the interlayer, and the outermost layer of the Halbach cylinder consist of 24, 30, and 36 permanent magnets, respectively.
- Remanence (B_r) value of NdFeB magnets was taken as 1.42 T.
- The distance between the two Halbach cylinders is 87 mm.
- The magnets' length is 42 mm and diameter is 10.3 mm.

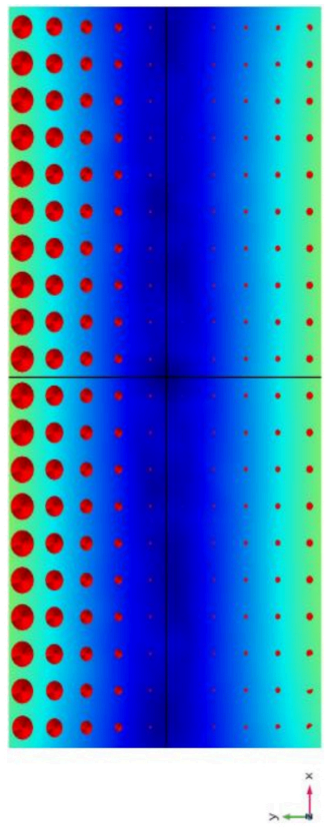
Design of Cylindrical Halbach Magnet System



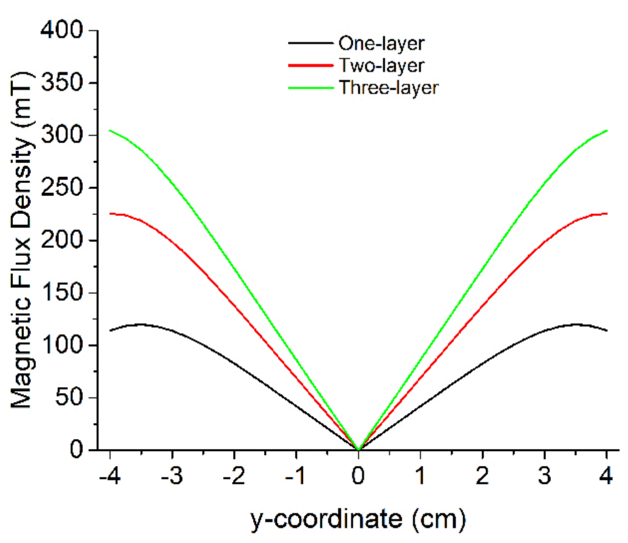
RESULTS

- Field-Free Line (FFL) was generated along the x-axis.
- The magnetic flux density on the x-axis at the FFL was obtained as 0.5 µT at single-layer design (the innermost layer), 0.6 µT at two-layer design, and 0.7 µT at three-layer design.
- It was observed that as the number of layers increases, the magnetic flux density, and gradient field strength increase on the y-axis.
- Similarly, gradients on the y-axis were obtained as 4.2 T/m at single -layer, 6.9 T/m at two-layer, and 8.7 T/m at three-layer design.
- The results show that the gradient values were stable along 35 mm at one-layer design, 45 mm at two-layer, and 50 mm at three-layer design, and the achieved **homogeneity was above 95%.**

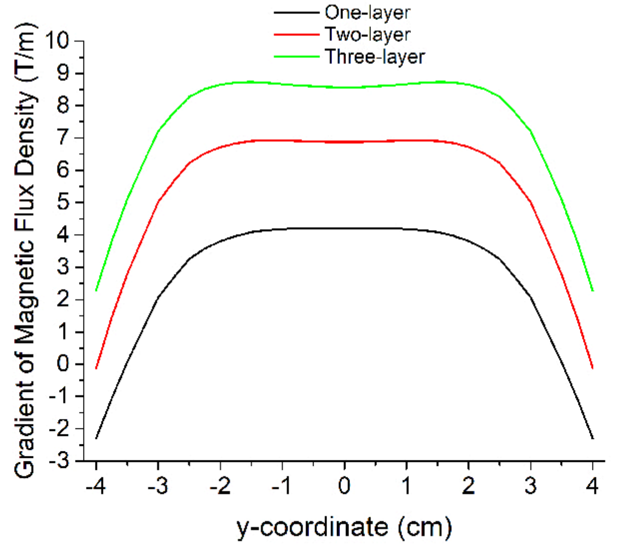
Selection field setup along x-axis to generate the FFL



Magnetic Flux Density along y-axis for each layer of the magnets



Gradient Field along y-axis for each layer of the magnets



- Three-layer Halbach magnets produced the highest magnetic flux density, and gradient field strength.
- Three-layer design is superior to the stability, and resolution since spatial resolution strongly depends on gradient field strength.

CONCLUSIONS

- In this work, FFL was successfully modeled using multiple Halbach rings consist of permanent magnets.
- A system of multiple layers of Halbach magnet have significant effects on FFL performance.
- Implementation of drive field using permanent magnets, coils, and analyzing the FFL performance based on different parameters (i.e., shape, length, size) will be the future goal of this study.

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