International Journal on Magnetic Particle Imaging
Vol 6, No 2, Suppl 1, Article ID 2009012, 3 Pages

Proceedings Article

Estimation of FFP accuracy in an MPI scanner with rotating magnets in Halbach arrangement

M. Schoger[1] · A. Hetznecker[1] · U. Heinen[1,*]

[1]Fakultät für Technik, Hochschule Pforzheim, Tiefenbronner Straße 65, 75175 Pforzheim, Germany
[*]Corresponding author, email: ulrich.heinen@hs-pforzheim.de

Abstract
Possible arrangements for the encoding/excitation magnets in an MPI system with rotating permanent magnets were investigated regarding their sensitivity towards magnet misalignments and magnet interference. A slight interaction between neighboring magnet pairs is observed as well as a 179µm/° FFP shift in case of magnet rotation. The use of a Halbach type array further increases the encoding gradient field strength.

I Introduction

Recently, a novel system architecture for fast Magnetic Particle Imaging has been proposed in which the standard setup of separate selection and drive fields driven by electric currents is replaced by an arrangement of permanent magnet pairs mounted on a rotating wheel (RotoMPI, see figure 1) [1]. Each magnet pair generates a separate Field Free Point (FFP), which traces a circular path during wheel rotation. By lateral displacement of the magnet pairs, similarly displaced FFP tracks are generated which together allow for scanning of a 2D area or a 3D volume located between detection coils mounted on the instrument frame. The novel setup allows for strong gradient fields and a variable speed excitation approaching the encoding speed of conventional MPI scanners.

Since band-stop filtering of the excitation signal is not possible in the novel setup due to a non-sinusoidal excitation, a cancellation approach was proposed where magnet pairs on opposite sides of the rotating wheel are carefully aligned to induce identical but phase-inverted signals in two separate sets of pickup coils mounted on opposite sides of the scanner. For successful cancellation of the induced background signals, the magnet position and orientations must be fine-tuned with great accuracy. Moreover, the encoding magnet pairs are placed in close proximity to each other, and it can be expected that their lateral displacement also influences the positing of neighboring FFPs, thus adding complexity to the task of accurate FFP positioning and optimization of signal cancellation.

In the present contribution, we report a simulation study to assess the required accuracy of magnet placement and orientation for successful implementation of the proposed cancellation scheme. Furthermore, the use of a Halbach type arrangement [2] of the magnets was checked to establish the possible gains in gradient strength. The principal results of the simulation study were verified experimentally.

II Material and methods

II.I Simulations

All field simulations were carried out using the open-source FEM package FEMM 4.2 [3], which supports sim-

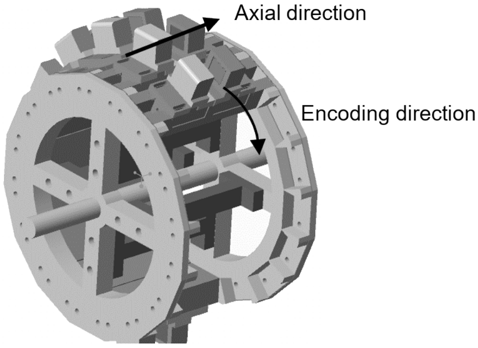

Figure 1: Pairwise arrangement of encoding magnets on a rotating wheel.

ulations of problems with planar or rotary symmetry. To study the FFP positions of adjacent magnet pairs with lateral offsets, a planar geometry corresponding to a rotating wheel with infinite diameter was chosen. Asymptotic boundary conditions were used with a 200 mm radius for the simulation boundary around the simulation center. This was verified to be sufficient to generate reproducible simulation results in the central FFP region. To obtain a detailed field map, 100 additional control points were placed in the FFP region to enforce a fine-grained computation mesh in the region of interest.

In each simulated setup, a series of cubic NdFeB-Magnets (N42) with an edge length of 20 mm were arranged pairwise with a pole gap of 20 mm to generate a sequence of five FFPs with alternating polarity. The distance between adjacent magnet pairs was set to 30 mm. Profiles of the flux density around the FFP of the central pair were then extracted and analyzed for the exact FFP location and gradient strength. The full setup is shown in figure 2a.

The simulation started with an initial setup including pairs 1,2,3,4, and 5 with no lateral displacement. It was verified that the central FFP is located exactly in the center of the magnet pair 3. As a second setup, the four outer magnet pairs were each shifted individually in axial direction to generate an arrangement suitable for spatial encoding. Pair 1 was shifted 1mm to the right, pair 2 4mm to the left, pair 4 3mm to the right, and pair 5 2mm to the left. This is representative of a typical arrangement with minimized imbalance. The central region was inspected for changes of the FFP position due to the asymmetric arrangement.

In a second series of simulations, the right magnet of pair 3 was rotated anti-clockwise in steps of 1° to simulate a misalignment or imperfect magnetization. Again, the influence on the FFP position was recorded.

Finally, additional 20mm cube magnets (NdFeB, N42) were placed in positions 1A to 4A between the encoding magnets to achieve a Halbach type arrangement [2]. Their axial displacement was set to the average displacement of the adjacent encoding magnets (see figure 2a).

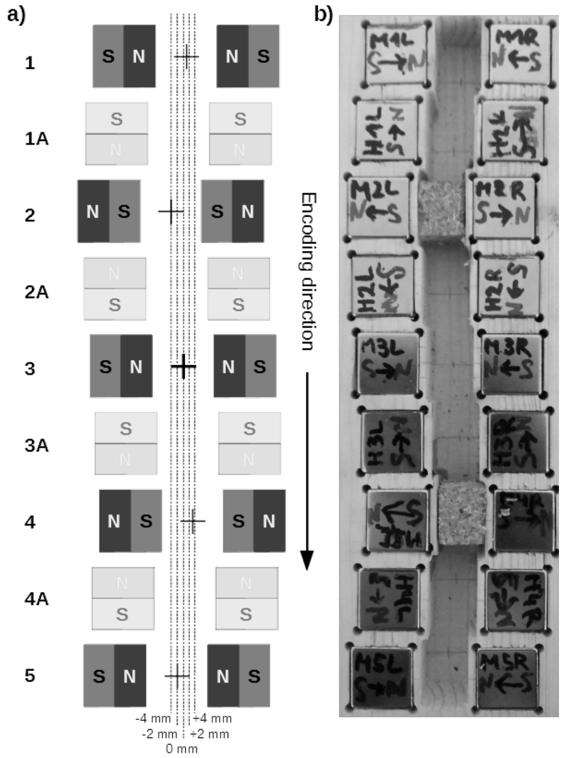

Figure 2: a) Visualization of magnet arrangement. The theoretical position of the FFPs are marked with + signs. b) Experimental realization of the encoding array.

The resulting shift of the central FFP was recorded and the field gradient in encoding direction determined.

II.II Experimental verification

The final Halbach type arrangement was assembled from cube magnets (Magnetladen Seiler GmbH) which were mounted in a wooden frame with precut holes (see figure 2b). A 3-axis hall sensor (Lakeshore Cryotronics Teslameter F71) was mounted on a 3-axis linear unit (Bohr-Fräsmaschine BF 46 Vario, Optimum Maschinen) and then used to scan flux density profiles in the central FFP region.

III Results and discussion

The axial shift of magnet pairs for spatial encoding has a notable influence on the position of neighboring FFPs. The -4mm/+3mm displacement of pairs 2 and 4 described in the previous section causes a 50 µm shift of the central FFP to the left (axial direction) and 13µm towards pair 4 (encoding direction).

A tilt of an encoding magnet causes an FFP shift in both axial and encoding direction. For small tilts, a linear dependence of the total FFP shift on the tilt angle was ob-

10.18416/ijmpi.2020.2009012

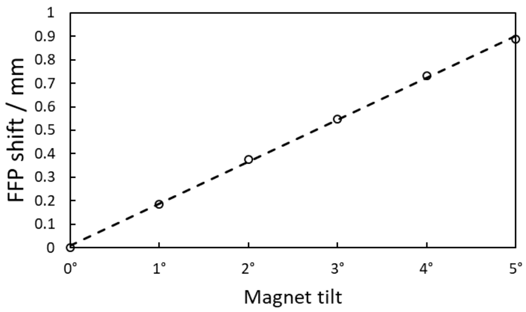

Figure 3: Total FFP shift as a function of magnet tilt. The dashed line has a slope of 179 µm/°.

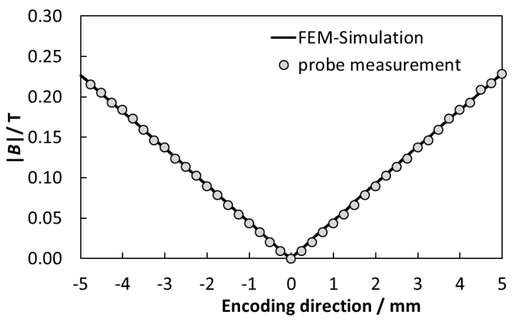

Figure 4: Simulated and experimental field profiles are in excellent agreement with a standard deviation of approx. ±1.5mT (1σ) to each other.

served with a proportionality constant of approximately 179µm/° (see figure 3).

For a 20mm magnet, a tilt of 5° corresponds to a 2mm movement of one magnet side, which is easily handled by a simple screw mechanism.

The addition of intermediate magnets for a Halbach type arrangement increases the flux density gradient in encoding direction from 35 T/m to 46 T/m. Only negligible shifts in FFP position are observed if a sufficiently large array is simulated. Measured and simulated flux density profiles are in excellent agreement (Figure 4).

IV Conclusions

The presented Halbach type magnet arrangement achieves a field gradient of 46 T/m in the encoding direction for a pole gap of 20 mm, which permits a maximum Field-Of-View of approximately 8 mm allowing for a 1 mm gap between sample and magnets. The dependence of the FFP positions on magnet misalignments and on neighboring magnets implies the need for a tedious calibration. This poses an engineering challenge to design a finely tunable mechanism for compensation of such deviations, e.g. by a set of blocking micro-screw flights. On the positive side, this strong orientation dependence provides an excellent means to compensate for FFP shifts due to imperfect magnetizations and due to interactions between neighboring pairs in the encoding arrangement.

Author's Statement

Research funding: The authors state no funding involved. Conflict of interest: Authors state no conflict of interest.

References

[1] I. Harbi, W. Schneider, D. Gann, J. Franke, U. Heinen, MPI Scanner with Rotating Permanent Magnets, IWMPI Hamburg 2018

[2] K. Halbach, Design of Permanent Multipole Magnets with Oriented Rare Earth Cobalt Materials, Nuclear Instruments and Methods, 168, 1-10, 1980.

[3] D. Meeker, Finite Element Method Magnetics, Version 4.2, 2018, http://www.femm.info