International Journal on Magnetic Particle Imaging
Vol 8, No 1, Suppl 1, Article ID 2203011, 3 Pages

Infinite Science Publishing

Proceedings Article

Fully mechanical driven Traveling Wave MPI

L. Mirzojan[a,*] · M. A. Rückert[a] · C. Greiner[a] · A. von Boehn[a] · T. Kampf[a,b] · V. C. Behr[a] · P. Vogel[a]

[a]Department of Experimental Physics 5 (Biophysics), University of Würzburg, 97074, Würzburg, Germany
[b]Department of Diagnostic and Interventional Neuroradiology, University Hospital Würzburg, 97080, Würzburg, Germany
[*]Corresponding author, email: Liana.Mirzojan@physik.uni-wuerzburg.de

Abstract

Magnetic Particle Imaging (MPI) is a novel imaging technique utilizing time-varying magnetic fields to determine the distribution of superparamagnetic iron-oxide nanoparticles in 3D. The usage of electrical coils for the generation of the desired strong magnetic field gradient as well as the time-varying magnetic fields allows flexible and fast imaging, but the corresponding high energy consumption also requires sophisticated cooling. The usage of permanent magnets provides the advantage of generating high magnetic field gradients without requiring electrical power and cooling, but also brings limitations with respect of flexibility and the size of the field of view. A novel approach utilizing rotatable Halbach rings is introduced, which overcomes the restrictions of static permanent magnet designs and provides the flexibility of a mechanically driven Traveling Wave MPI scanner.

I. Introduction

MPI is an imaging modality for direct visualization of superparamagnetic iron-oxide nanoparticles (SPIONs) in 3D [1]. It relies on the nonlinear magnetization response of SPIONs to time-varying magnetic fields. For imaging the SPION distribution, a field free region (field free point – FFP or field free line – FFL) in the form of a strong magnetic field gradient is moved on a known trajectory through the field of view (FOV) to scan the entire volume step-by-step. In the last decade, multiple MPI scanner approaches were introduced, often using electrical coils for the generation of fast-moving gradient fields [2]. To generate strong magnetic field gradients, the amplifiers driving the coils of the MPI scanner require high power. Furthermore, the amplified signal has to be filtered by high power passive filters to suppress higher harmonics directly generated by the amplifiers. An ineffective filtering not only reduces the available signal-to-noise (SNR) in the receive chain, but also requires sophisticated hardware knowledge.

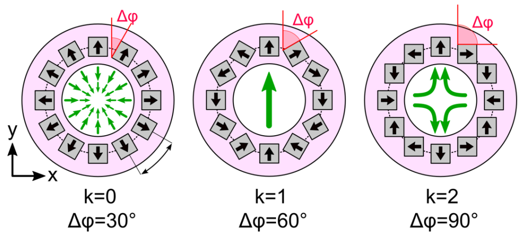

Figure 1: Halbach rings consist of multiple permanent magnets assembled on a ring with a specific angle generating different magnetic field configurations.

To reach a higher SNR, MPI scanner concepts utilizing permanent magnets, such as Halbach rings [3], have been demonstrated [4, 5, 6]. Halbach rings can be used in nuclear magnetic resonance (NMR) devices to generate strong and homogeneous magnetic fields without the need of electrical power [7]. Furthermore, it had been shown, that the asynchronous toroidal rotation of two

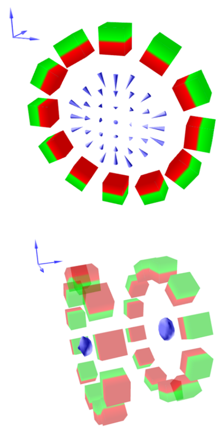

Figure 2: Top: two Halbach rings (k=0) with different poloidal rotation angle. Bottom: by positioning both rings at a fixed distance and under continuous synchronous vortex rotation, two field free points (blue spheres) are generated traveling along the symmetry axis (Traveling Wave approach [9]).

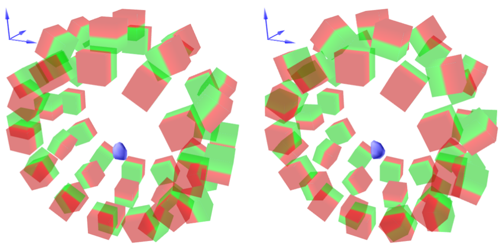

Figure 3: Additional Halbach rings (configuration k=1) assembled in the center of the k=0 rings and counter rotated with different frequencies f_2 and f_3 to steer the FFPs along a rose trajectory. Combining all rotations, a full coverage of the FOV can be reached.

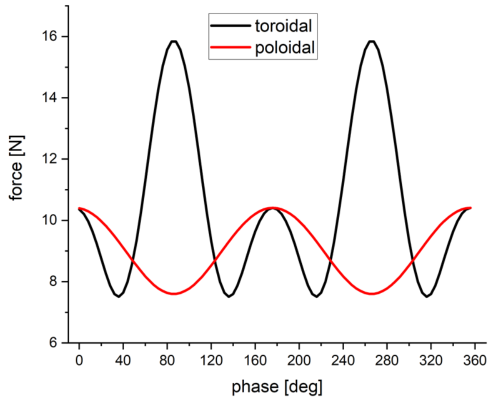

Figure 4: Simulation of the forces arising during a full 360° degree toroidal and poloidal rotation of a Halbach ring (k=0).

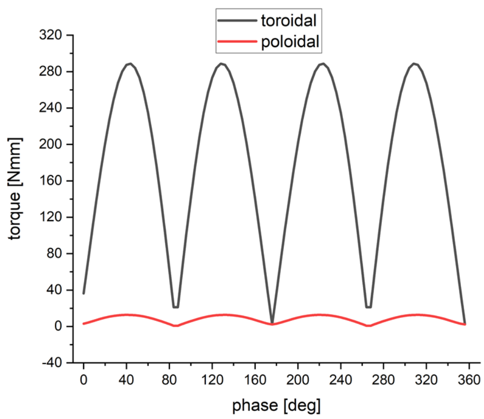

Figure 5: Simulation of the torques arising during a full 360° degree toroidal and poloidal rotation of a Halbach ring (k=0).

Halbach rings with different configurations (see Fig. 1) can be performed without the need of strong forces [8].

In this abstract, a novel approach for Traveling Wave MPI scanners (TWMPI) [9] using mechanically rotating Halbach rings is demonstrated.

II. Material and methods

The different configurations shown in Fig. 1 can be generated by rotating each magnet around their local z-axis by the desired angle $\Delta\phi$.

The k=0 Halbach ring shows a field free point at the center. With the addition of poloidal rotations therefore each magnet rotating around its local x-axis, the magnetic field can be changed (Fig. 2 top).

For a mechanical TWMPI scanner, two Halbach rings in the k=0 configuration, performing a continuous synchronous poloidal rotation with a phase shift of 180° degree, are assembled in a distance d. This synchronous rotation with frequency f_1 generates two FFPs moving along the symmetry axis of the scanner (see Fig. 2 bottom) [9].

Two additional Halbach rings with k=1 configuration, which counter-rotate around the z-axis with frequencies f_2 and f_3, are utilized to move the FFP along a rose trajectory covering the entire FOV (see Fig. 3).

III. Results and discussion

Halbach arrays are known for their high magnetic field strength, which makes it difficult to build such systems or even build rotatable arrays.

To investigate that issue, initial simulations have been performed to evaluate the forces and torques arising in such systems using a home-built software [10].

The results can be seen in Fig. 4 and Fig. 5, where the arising forces dramatically decrease for the poloidal rotation and the torques decrease slightly. However, for smooth rotations of all components, the forces between

10.18416/ijmpi.2022.2203011

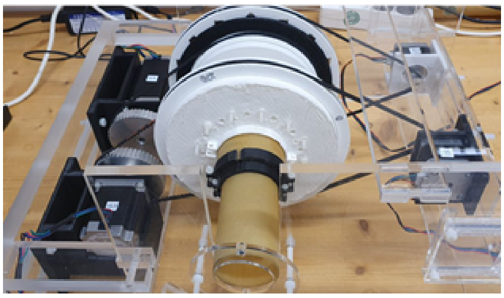

Figure 6: Fully implemented mechanical driven Traveling Wave MPI.

the magnets should not show strong changes (Fig. 4), because this would cause high torques in the bearings (Fig. 5).

Furthermore, the full scanner, with all four rings, can be seen in Fig. 6.

IV. Conclusions

A fully mechanically driven Traveling Wave MPI scanner approach covering a full 3D volume is presented. Building all gradients of the MPI system from permanent magnets allow for high gradient fields combined with low energy consumption.

Acknowledgments

Research funding: The work was partially supported by the German Research Council (DFG) (grant numbers: VO-2288/1-1, VO-2288/2-1 and BE-5293/1-2).

Author's statement

Conflict of interest: Authors state no conflict of interest.

References

[1] B. Gleich & J. Weizenecker, Tomographic Imaging using the nonlinear response of magnetic particles, Nature, 435, 1214-7, 2005.

[2] T. Knopp, et al., Magnetic Particle Imaging: From Proof of Principle to Preclinical Applications, Phys Med Biol, 62(14), R124, 2017.

[3] K. Halbach, Design of permanent multipole magnets with oriented rare earth cobalt material, Nucl Instr Meth Phys Res, 169(1), 1-10, 1980.

[4] H. Bagheri, et al., A mechanically driven magnetic particle imaging scanner, Appl Phys Lett, 113:183703, 2018.

[5] M. Weber, et al., Novel Field Geometry featuring a Field Free Line for Magnetic Particle Imaging, Int Journal on Magn Imag, 4(2):1811004, 2018.

[6] P. Vogel, et al., Magnetic Particle Imaging meets Computed Tomography: first simultaneous imaging, Sci Rep, 9:12627, 2019.

[7] Raich & Blümler, Design and construction of a dipolar Halbach array with a homogeneous field from identical bar magnets: NMR Mandhalas, Concept Magn Reson B, 23B(1), 16-25, 2004.

[8] C. Vitor, et al., Nested dipolar Halbach arrays for the determination of magnetorheological properties at variable magnetic field, Rheologica Acta, 50:441, 2011.

[9] P. Vogel, et al., Traveling Wave Magnetic Particle Imaging, IEEE TMI, 33(2), 400-7, 2014.

[10] P. Vogel, et al., 3D-GUI Simulation Environment for Magnetic Particle Imaging, Proc. on IWMPI (Lübeck), 95, 2016.