Magnetic Particle Imaging using Toroidal Vortex Rotation of Halbach Rings

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Abstract: Magnetic Particle Imaging (MPI) is a promising imaging technique utilizing time-varying magnetic fields to determine the distribution of superparamagnetic iron-oxide nanoparticles (SPIONs). Instead of using electrical coils for the generation of required magnetic fields, a novel approach with rotatable Halbach rings is introduced.

Introduction: MPI is a novel imaging modality for direct visualization of SPIONs. It relies on the nonlinear magnetization response of SPIONs on time-varying magnetic fields. For imaging and determining the SPION distribution, a field free point (FFP) created by a strong gradient is steered through the field of view (FOV) to scan the entire volume point-by-point for [1]. Multiple MPI scanner approaches were introduced, where most are using electrical coils for the generation of fast-moving gradient fields [2]. To reach a higher signal-to-noise ratio (SNR), MPI scanner concepts utilizing permanent magnets, such as Halbach rings [3, 4], has been demonstrated. Halbach rings are used in nuclear magnetic resonance (NMR) devices to generate strong and highly homogeneous magnetic fields without the need of electrical power [6]. To transfer the approach to MPI, configurations generating strong gradients have been found [4, 7].

In this abstract, a novel approach for Traveling Wave MPI scanners (TWMPI) [5] using mechanically rotating Halbach rings is shown.

Methods: For a mechanical TWMPI scanner, two coaxial Halbach rings (*k*=0 configuration) performing a synchronous vortex ring rotation with a phase shift of 90 degree are assembled in a distance *d*. This synchronous rotation with frequency f_1 generates an FFP moving along the symmetry axis of the scanner (see Fig. 1 top).

Two additional Halbach rings with *k*=1 configuration, which counter-rotate along the z-axis with frequencies f_2 and f_3, are utilized to move the FFP along a spiral trajectory through the FOV (see Fig. 1 bottom).

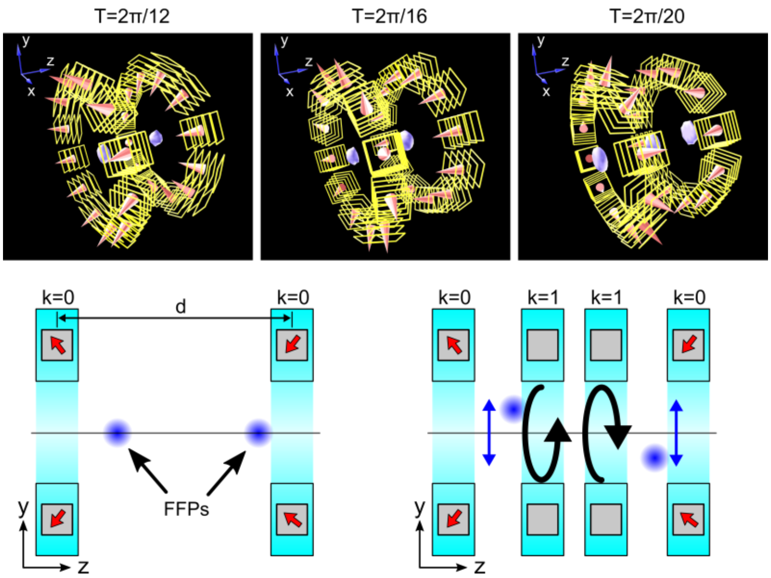

Figure 1: Top: The time series above shows the rotation of the Halbach rings at different times points. The red arrows indicate the direction of each magnet, the blue area represents the area with lower magnetic fields: field free points (FFP). **Bottom left:** cut through the rings (*k*=0) generating the traveling FFPs along the symmetry axis. **Bottom right:** additional Halbach rings (*k*=1) rotating around the z-axis steer the FFPs along a spiral trajectory through the FOV.

Discussion and Conclusion: 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.

References: [1] Gleich & Weizenecker, Nature (2005). [2] Knopp, PMB (2017). [3] Halbach, Nucl Instr Meth Phys Res (1980). [4] Bagheri, Appl Phys Lett (2018). [5] Vogel, IEEE TMI (2015). [6] Raich & Blümler, NMR Mandhalas (2004). [7] Vogel, Nature Sci Rep (2019).