Magnetic Field Generation for Multi-Dimensional Single-Sided Magnetic Particle Imaging

T. F. Sattel[1], S. Biederer[1], T. Knopp[1], and T. M. Buzug[1]
[1]Institute of Medical Engineering, University, Luebeck, Germany

Introduction: Magnetic particle imaging (MPI) is a method capable of determining the spatial distribution of super-paramagnetic iron oxide particles (SPIOs) at potentially high sensitivity, high spatial and high temporal resolution [1,2,3]. The feasibility of a single-sided coil arrangement for field generation and reception of the particle signal was shown in [4]. There, the object of interest is positioned in front of a scanner head and not inside a scanning chamber. Consequently, the total size of the object to be examined does not matter whereas the scannable field of view (FOV) is still limited. So far, applying the single-sided concept, a 1D-imaging device has been implemented [4] which allows only for scanning a single line in space. In this contribution, different coil arrangements are shown, which extend the existing setup towards 2D imaging.

Methods: For spatial encoding, MPI applies a static magnetic field, which provides a field-free point (FFP). In Fig. 1, it is generated by two concentrically mounted coils carrying currents in opposite direction. For particle excitation, the FFP is steered through the volume whereas its trajectory defines the scannable FOV. By superimposing an alternating current on the inner coil, the field distribution changes and moves the FFP along the coil axis. To span a 2D FOV, the generation of perpendicular magnetic fields is required. Obviously, this can be achieved by adding a perpendicularly orientated rectangular coil as shown in Fig. 2a). Applying a current of slightly different frequency than on the inner coil, a 2D Lissajous trajectory is achieved [5]. Since almost only the current flowing in the upper bar contributes to the desired magnetic field, this coil setup is inefficient. Alternatively, a pair of D-shaped coils can be used (Fig. 2b, Fig. 3). Like the rectangular coil, they generate a magnetic field which is in parallel to the scanner front within the FOV. Since the current return path is shorter in this configuration, the power losses are reduced. Another advantage is that, using the D-shaped coils, the scanner head can be implemented very flatly.

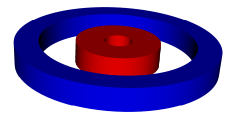

Fig. 1: Original single-sided coil setup [4].

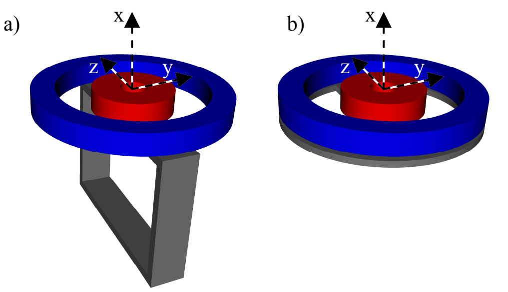

Fig. 2: Extension to the original setup (red and blue coil) by **a)** a rectangular coil and **b)** a set of D-shaped coils, which is shown separately in Fig. 3.

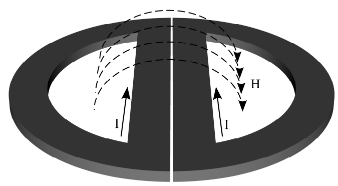

Fig. 3: A set of D-shaped coils. Current flow and magnetic field direction within the FOV are indicated by arrows.

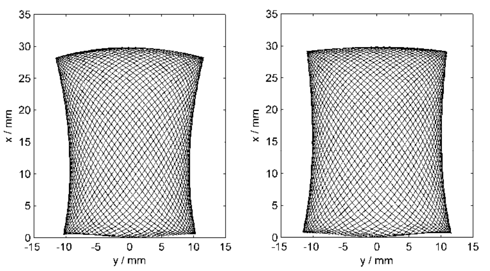

Fig. 4: 2D FFP trajectory using a rectangular coil (left) a pair of D-shaped coils (right) for FFP-movement in y-direction.

Results: Both presented setups meet the demands with respect to the geometry of the generated magnetic field. Thus, the FOV of a single-sided MPI device can be extended to a 2D area. Its shape depends on the field distribution, which is defined by the coil geometries themselves. The size of the covered area depends on the applied currents. Here, the aim was to create a rectangular FOV of about 20 x 30 mm directly in front of the coil setup. Fig. 4 shows the resulting FFP trajectories of the two different coil setups. As can be seen, the resulting Lissajous curves show a slight deformation due to field inhomogeneities, which is more pronounced close to the scanner front.

Discussion/Conclusion: It was shown that an extension to the single-sided 1D imaging device is feasible, which provides 2D imaging, without harming the single-sided concept. The setup including the D-shaped coils has the advantage that the scanner device remains flat. Furthermore, when implementing a 3D scanner device, an additional pair of D-shaped coils having the same geometry can easily be added in behind, rotated by 90°. For reasonable 2D image reconstruction, it is essential to detect not only one but two components of the particle magnetization vectors. Therefore, one either uses the additional coils not only for field generation but also for receiving the particle signal or one applies dedicated receive coils of similar geometry. Here, the flat design of the D-shaped coil pairs becomes relevant since they can be easily stacked behind or in front of the original setup. Depending on the intended application, the preferable coil setup may be further optimized with respect to trajectory geometry, power loss or scanner head size. Multi-dimensional single-sided MPI is the next step in development for small, hand-held or larger in-table MPI devices offering a broad field of applications.

References:
[1] B. Gleich and J. Weizenecker. 2005, Nature, 435:1214-1217.
[2] B. Gleich et al. 2008, PMB, 53:N81-N84, 2008.
[3] J. Weizenecker et al. 2009, PMB, 54:L1-L10.
[4] T. F. Sattel et al. 2009, JPhysD, 42:1-5.
[5] T. Knopp et al. 2009, PMB, 54:385–397.