Open Coil Arrangement for Interventional Magnetic Particle Imaging

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Introduction: Magnetic particle imaging (MPI) is a method to determine the spatial distribution of super-paramagnetic iron oxide particles (SPIOs) at potentially high sensitivity, high spatial and high temporal resolution [1,2,3]. For magnetic field generation and particle signal reception, electromagnetic coils are used. In their paper [1], Gleich and Weizenecker proposed a tube-like scanner setup as it is illustrated in Fig. 1. So far, a scanner device has been implemented, which fits a mouse, but the aim is to scale it up to finally image a human body. In many cases, there might be the need to access the patient while acquiring images. The aim of this work is to find a new coil geometry, which provides this additional feature without or with only little loss in image quality and only little additional expenses.

Methods: Fig. 1 illustrates the original coil setup. The coils plotted in green generate both, the selection field, which provides the field-free point (FFP) essential for the MPI method and the drive field in x-direction. By oscillation of the drive field, the FFP can be moved in x-direction. To scan a 3D volume (field of view, FOV), the FFP has to be steered along a trajectory in all three dimensions. Therefore, the coils plotted in red and orange generate drive fields in y- and z-direction, respectively. To get lateral access to the object of interest, these have to be replaced by other coil geometries, which are capable of generating magnetic fields within the FOV similar to the original ones. As illustrated in Fig. 2, pairs of D-shaped coils can be used for this purpose. A set of two such coils generates a strong magnetic field orientated in y-direction. Another set is mounted, rotated by 90°, such that the generated field is orientated in z-direction (Fig 3). The current amplitudes applied to these coils are adapted to obtain a trajectory similar to the original one. For illustration, 2D trajectories are plotted, which are obtained when one of the three oscillating fields is set to zero (Fig. 4). For reasonable 3D image reconstruction, receive coils are required, which provide sensitivity profiles perpendicular to each other within the FOV. For this purpose, again, pairs of D-shaped coils are appropriate irrespective whether the identical coils are used for field generation as well as for particle signal reception or if dedicated receive coils are used.

Results: The proposed open coil setup allows steering the FFP along a 3D trajectory, while allowing full access to the specimen. Fig. 4 shows the resulting 2D trajectories, when choosing the coil currents such that approximately the same FOV is covered. Assuming perfect field geometries, the trajectories would be Lissajous curves [4]. Both, the original scanner setup as well as the open scanner setup, provide inhomogeneous magnetic fields. This results in deformation of the Lissajous curves. Comparing the trajectories in xy-plane, the covered area is no longer concave but convex, which affects the reconstructable FOV. Using the D-shaped coils, the trajectory in yz-plane better resembles the ideal Lissajous curve most notably at its border. This could lead to better image quality at the border regions of a rectangular FOV. However, compared to the original y- and z-coils, the total power loss within the D-shaped coils is about a factor of three higher.

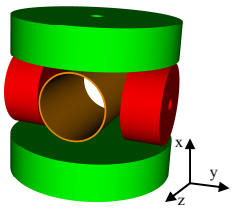

Fig. 1: Original coil setup.

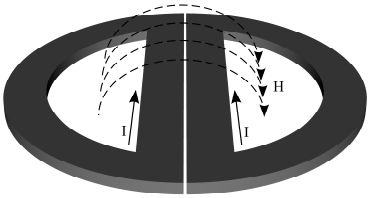

Fig. 2: A set of D-shaped coils. Current flow and magnetic field direction within the FOV are indicated by arrows.

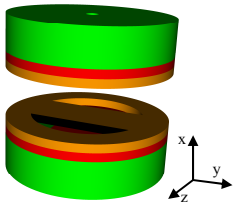

Fig. 3: Open MPI: using two sets of D-shaped coils.

Discussion/Conclusion: A new coil geometry for 3D MPI is introduced, which provides lateral access to the patient and, thus, allows for interventional MPI. The proposed coil geometry is investigated by comparing the quality of the FFP trajectories of both setups, which give promising results. In terms of power loss, the introduced sets of D-shaped coils are worse but do not exceed the power losses of the selection field generation, which is identical in both setups. With this contribution, the feasibility of an open MPI system is shown. Further coil geometry optimization may improve the results.

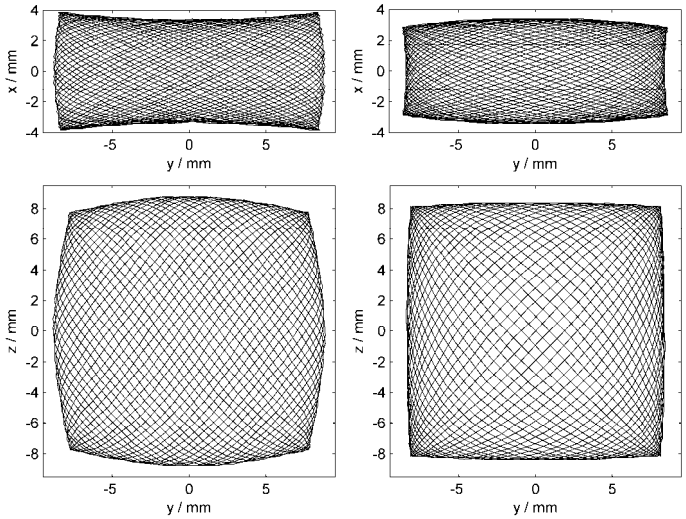

Fig. 4: 2D FFP trajectories in xy-plane (top) and yz-plane (bottom) using the original setup (left) and the modified setup (right).

References:

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