Efficient Generation of a Magnetic Field-Free Line

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Introduction: Magnetic particle imaging (MPI) is a quantitative imaging technique capable of determining the spatial distribution of super-paramagnetic nanoparticles (SPIOs) [1, 2, 3]. For spatial encoding, MPI uses a field-free point (FFP), which is moved through the region of interest. Due to saturation effects, only nanoparticles in the close vicinity of the FFP contribute to the voltage signals induced in receive coils. Recently, an alternative encoding scheme was proposed, which considerably increases the sensitivity of MPI by taking advantage of a field-free line (FFL) [4]. During data acquisition, the FFL is moved rapidly back and forth while rotating slowly. Hence, the encoding scheme for FFL imaging is similar to that used in computed tomography. In Fig. 1, a comparison of the FFP field and the FFL field is provided. Although the advantages of FFL imaging are obvious, the practicability of this method was questioned by its inventors [4]. This was due to the fact that their FFL coil configuration had a considerably higher power loss than an FFP scanner of equal size and gradient strength. More precisely, the power loss was thousand times higher, preventing a realization of the FFL concept. In this work, we show that practical implementations of the FFL concept become indeed feasible since essential improvements of the coil setup result in a far higher efficiency.

Methods: The FFL scanner introduced in [4] consists of 32 small coils positioned at equidistant angles on a circle around the center of the setup. The currents are chosen such that two opposing coils have the same current flowing in opposite direction, i.e. the setup consists of L = 16 Maxwell coil pairs. The currents contain a static and a dynamic part, of which the latter depends on the direction of the FFL. To generate an FFL with an angle α to the x-axis, the currents of the l-th coil pair are chosen as $I_l = A(3/2 - \cos(2\varphi_l - 2\alpha))$. Here, $\varphi_l = \pi l / L$ denotes the angle of the l-th coil pair and A denotes the current amplitude, which determines the gradient strength of the field. In this work, we propose to reduce the number of coils used to generate the FFL. Instead of L = 16, we use L = 4 Maxwell coil pairs. In Fig. 2 a sketch of the proposed coil configuration is illustrated. Using fewer coils has the advantage that the efficiency of the device is considerably increased. This is due to the fact that the size of each coil can be increased when using fewer coils resulting in a lower power loss.

Results: To assess the efficiency of the FFL coil configuration for different numbers of Maxwell coil pairs, magnetic field simulations are carried out using the Biot-Savart law. The coils are located on a circle of 1 m diameter and have a diameter such that two neighboring coils do not intersect. The current amplitude is adapted to generate an FFL with 1.0 $Tm^{-1}\mu_0^{-1}$ gradient strength in perpendicular direction to the FFL. The power loss of the setup is compared to that of an FFP scanner of equal size and gradient strength. For L = 16, the relative power loss is a factor of 1026, whereas for L = 8, this factor is 6.5, which denotes a major improvement.

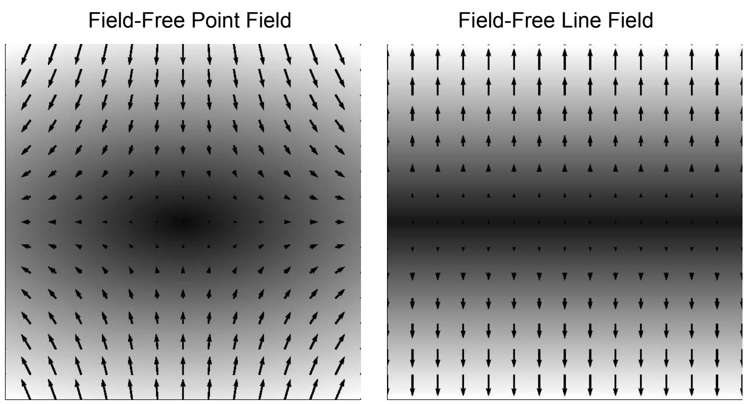

Fig. 1: Comparison of the FFP field and the FFL field in xy-plane.

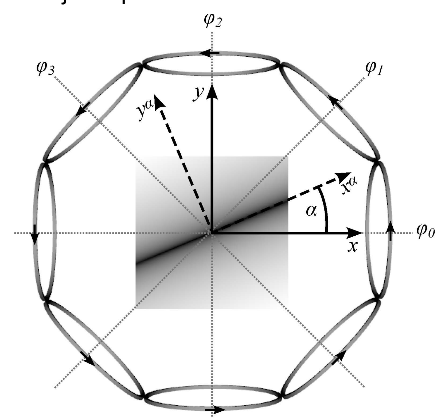

Fig. 2: Coil setup for generating a rotating FFL.

Discussion/Conclusion: In the present work, we have shown that the efficiency of the FFL geometry proposed in [4] can be considerably improved by using fewer Maxwell coils. Therefore, the FFL is not only a theoretical concept but is indeed practically feasible. Actually, the coil setup shown in Fig. 2 can also be used as an FFP scanner, so that combined FFP-FFL scanner setups are possible.

References:
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