Simulation of a Single-Sided Magnetic Particle Imaging Device with COMSOL Multiphysics®

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Abstract

Introduction
Magnetic Particle Imaging (MPI) was presented by Gleich and Weizenecker in 2005 [1]. In 2009 Sattel et al. presented an innovative single-sided scanner design [2].

For the MPI imaging process, superparamagnetic iron oxide nanoparticles (SPIONs) are used as tracer material. The particles are excited by a sinusoidally varying magnetic field. A field-free point (FFP) is generated by the superposition of two magnetic fields. The FFP is important for the imaging process, since only the SPIONs in the FFP and its direct neighbourhood are essential for the received signal.

In figure 1, the magnetisation of nanoparticles at different locations within the measurement volume is demonstrated. The first column shows three points with respect to the gradient strength. The magnetisation curve of the SPIONs and the excitation field are illustrated in the second column. The consequential magnetisation is depicted in the third column, whereas in the fourth and fifth column, the induced voltage in the receive coil and the spectrum is shown respectively. According to the various distances between the sample positions and the FFP, the SPIONs are excited differently. Therefore, a spatial encoding is necessary.

Use of COMSOL Multiphysics®
In the following, COMSOL Multiphysics® is used to simulate the single-sided scanner. The single-sided scanner for 1D measurement consists of two different coils (figure 2). A direct current (DC) about 65A in the outer circular coil and a DC about 56A in the inner circular coil, which flows in opposite direction, are applied. By the superposition of the two magnetic fields an FFP is generated. An additional alternating current about 42A in the inner coil is necessary in order to create a drive field to move the FFP in one dimension in front of the scanner.

In the configuration, the simulation sphere diameter has a size of 0.2m. It specifies the simulation setting. The diameter of the outer coil is 0.14m. The sphere material is chosen as air and the coils consist of copper. The electrical conductivity of air is set to 0.1S/m to simplify the calculation. To create the magnetic fields of the circular coils the Multi-Turn Coil Domain in COMSOL Multiphysics® was used. The mesh is a triangular mesh.

Results

The results calculated with COMSOL Multiphysics® are realistic in terms of the accuracy of the magnetic fields. In figure 3, the single-sided MPI scanner and its magnetic field at the first time step, simulated in COMSOL Multiphysics®, is depicted. The arrows illustrate the total instantaneous solution of the different fields. In the illustrations the dark blue parts represent the FFP. Whereas, the other parts are based on their magnetic flux density intensity.

Conclusion
COMSOL Multiphysics® features the possibility to add D-shaped coils to the scanner geometry and to get an even more detailed solution by using a proper equation for the way of the current through the D-shaped coil. This work implicates new possibilities to simulate a whole MPI scanner setting. Further, it is feasible to examine the heat generation in the scanner as a bases for constructing a cooling system.

Reference

1. B. Gleich et al., “Tomographic imaging using the nonlinear response of magnetic particles,” Nature,vol. 435, pp. 1214–1217 (2005)
2. T. F. Sattel et al., “Single-sided device for magnetic particle imaging,” Journal of Physics D: Applied Physics, vol. 42, no. 2, pp. 1–9 (2009)

Figures used in the abstract

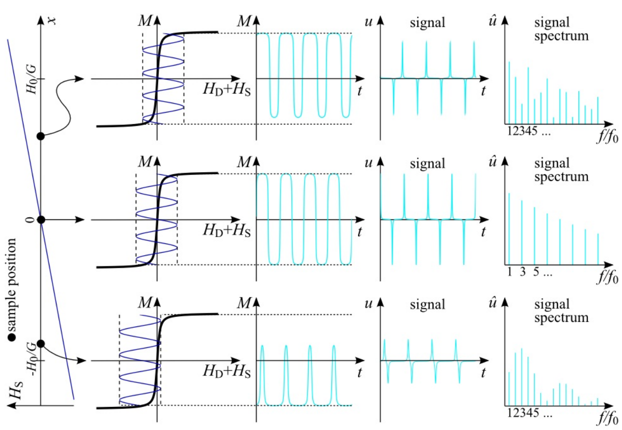

Figure 1: Figure 1: Dependency of the nanoparticle response with respect to the distance to the FFP.

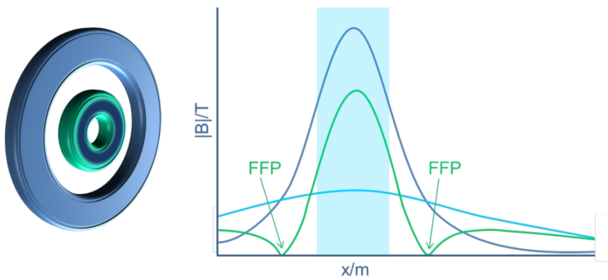

Figure 2: Figure 2: The Single-Sided Scanner geometry and the generated magnetic fields.

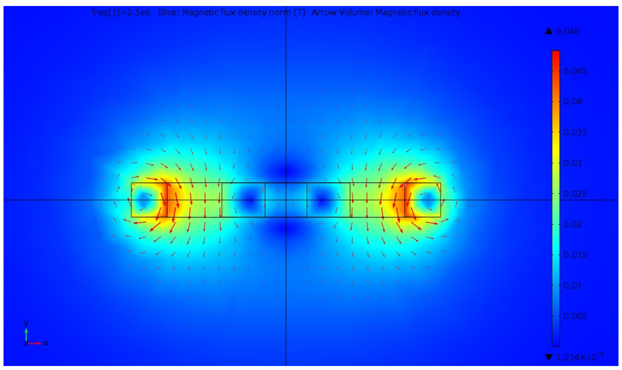

Figure 3: Figure 3: Single-sided MPI scanner and the generated magnetic field of the first time step simulated in Comsol.