

# SIMULATION STUDY OF A SINGLE-SIDED MAGNETIC PARTICLE IMAGING DEVICE

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**Abstract:** *Magnetic Particle Imaging (MPI) is a new imaging method, which was first presented by Gleich and Weizecker in 2005. Since then, there have been many innovations in MPI, such as the single-sided scanner design, introduced by Sattel et al. in 2009. Its major advantage lies in the optimised use regarding patient access. This contribution is concerned with the simulation of the single-sided design in Comsol Multiphysics® (Comsol), a commercial simulation software for physical processes.*

*This promotes the research into MPI, since the various capabilities of Comsol enables a more comprehensive simulation of the single-sided MPI scanner design.*

**Keywords:** *magnetic particle imaging, single-sided scanner, magnetic field, coil design, Comsol Multiphysics®*

## Introduction

The first MPI scanner was presented by Gleich and Weizecker in 2005 [1]. Since then, there have been many publications by different research groups related to MPI scanner devices [2, 3, 4]. In 2009 for instance, Sattel et al. presented an innovative single-sided scanner design [5].

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.

With the single-sided MPI scanner, a field-free point (FFP) is created by the superposition of two magnetic fields. The FFP is of great importance for the imaging process, since only the SPIONs in the FFP and its direct neighbourhood are essential for the receive signal.

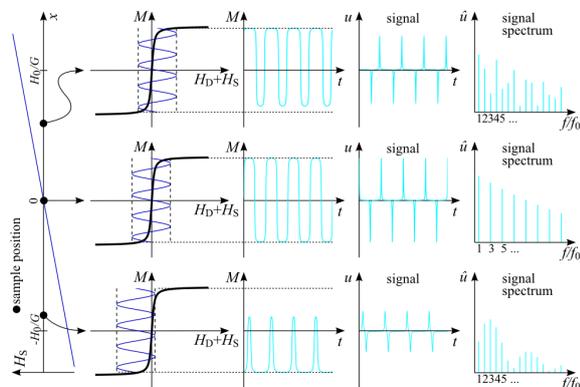


Figure 1: Dependency of the nanoparticle response with respect to the distance to the FFP.

In figure 1, the magnetisation of nanoparticles at different local points is demonstrated. The first column shows three various local points and the associated field strengths. Their magnetisation curve and the excitation field are illustrated in the second column. The consequential magnetisation is depicted in the third column, whereas in the fourth column, the induced voltage in the receive coil is shown. The voltage spectrum is expressed in the last column. According to the various distances between the sample positions and the FFP, the excitation field is different at each point and the SPIONs are excited differently. Therefore, the corresponding spectra differ and a spatial encoding is possible.

## Methods

*ScannerConf* is a software, developed at the Institute of Medical Engineering, to simulate magnetic fields in order to construct MPI scanners. *ScannerConf* has been used to simulate the single-sided MPI scanner and its simulations have already been compared to measurements [6]. In contrast to that, *Comsol* is a commercial FEM software providing plenty of different application areas. In the following, *Comsol* is used to construct the single-sided scanner and is compared to the simulations in *ScannerConf*.

The single-sided scanner geometry consists of four different coils. Two of them have a circular geometry built interleaved and two have a D-shaped geometry. A direct current (DC) about 65 A in the outer coil and a DC about 56 A in the inner coil, which flows in opposite direction, are applied. An alternating current (AC) about 42 A in the inner coil is necessary in order to create a drive field to move the FFP in one dimension. In the D-shaped coils, placed flat under the circular coils, the AC is about 80 A to move the FFP on a Lissajous trajectory [7].

In the configuration, the simulation sphere diameter has a size of 0.2 m. It specifies the simulation setting. The diameter of the outer coil is 0.14 m. The sphere material is chosen as air and the coils consist of copper. The electrical conductivity of air is set to 0.1 S/m to simplify the calculation. To create the magnetic fields of the circular coils the application *Multi-Turn Coil Domain* of *Comsol* was used. Creating the magnetic field of the D-shaped coils is more complex. While comparing different simulation methods for the D-shaped coils in *Comsol* with further results used by *ScannerConf* it follows that a modulation using the circular *Multi-Turn Coil Domain* is representative for the earlier used fields of the D-shaped coils. The mesh, which is used for the simulation with *Comsol*, is a triangular mesh

and the simulation is solved for 177214 degrees of freedom. Solving this operation, it is divided into a stationary step, solving the DC components of the model, and in a frequency-domain step, resolving the frequency-domain components.

## Results

The results calculated with *Comsol* are very realistic in terms of the accuracy of the magnetic fields. In figure 2, the stationary magnetic field of the single-sided MPI scanner simulated in *Comsol* is shown, whereas the appropriate simulation in *ScannerConf* is shown in figure 3.

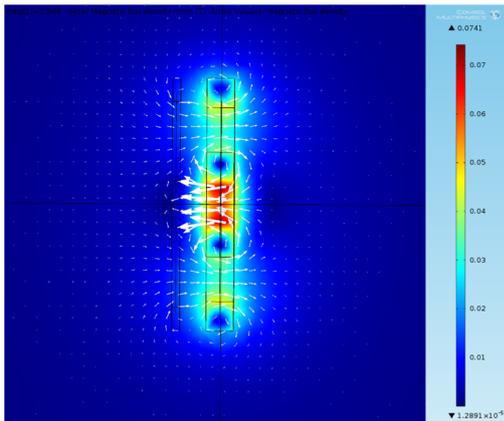


Figure 2: Single-sided MPI scanner and its magnetic field simulated in *Comsol*.

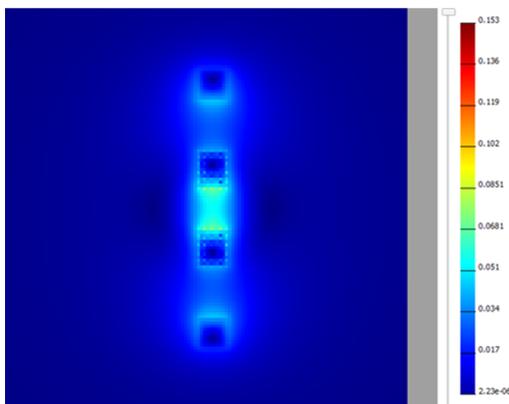


Figure 3: Magnetic field of the single-sided MPI scanner simulated with *ScannerConf*.

Apparently the values of the two different computations differ only about 5 mT, considering highest values in the inside of the inner coil. In figure 2, the single-sided MPI scanner and its static magnetic field, simulated in *Comsol*, is depicted. The arrows illustrate the total instantaneous solution of the different AC and DC fields. In figure 3, the magnetic field of the single-sided MPI scanner, assembled in *ScannerConf*, is shown. In both illustrations the dark blue parts represent the section, where the magnetic flux density approaches zero, whereas the other coloured, parts are based

on their magnetic flux density intensity.

## Discussion

The similarity of the two different modulation modes is of great significance. Both, the shape and the values of the results of *Comsol* and *ScannerConf* are essentially agreeing. Due to the comparison of the *ScannerConf* simulation with measurements [6], the *ScannerConf* values indicate very representative results. This fact, in particular confirms the quality of the *Comsol* results.

The small deflections between the different results could be explained by a simplification of the D-shaped coils. However, *Comsol* features the possibility 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. Because of *Comsol's* complexity, it is feasible to examine the heat evolution in the scanner and find a good way to apply a cooling system.

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