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First images obtained with a rabbit-sized Magnetic Particle Imaging scanner

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Abstract

The subject of this work is a magnetic-particle-imaging system featuring a field generator with an inner bore diameter of 180 mm. The scanner, which is large enough to accommodate small animals, is capable of generating a selection field either with a field free point or with a field free line. In this work, the imaging system is used to acquire two-dimensional data from a particle distribution using a field free point to record a system matrix. Finally, a plain particle phantom is measured to evaluate the imaging data and show the first two-dimensional image that is recorded with this setup.

I Introduction

A Magnetic-Particle-Imaging (MPI) system including a field generator with a bore diameter of 180 mm was developed over the past few years. The system is designed to acquire imaging data from small animals using a field-free-line (FFL) for the spatial encoding but can also be used as a field-free-point scanner (FFP). The system is capable of generating a two dimensional drive field with a magnetic-field amplitude of $\hat{B} = 15$ mT. The maximum achievable gradient of the selection field amounts to 0.8 T/m which leads to a field of view (FOV) with a diameter of 37.5 mm. By applying the FFP-encoding principle 1D- and 2D images where obtained. The measurement setup and imaging results are presented in this work.

II Material and methods

The main components in the scope of this work are the field generator, which is described in depth in [1], and a dedicated receive coil that is especially designed for this particular scanner to pick up the particle signal. A 1D- and a 2D system matrix (SM) were recorded and used to reconstruct a plain particle phantom.

II.I Field generator

The considered field generator consists of five components that are arranged in single layers. The outer three layers contain two electromagnetic quadrupoles and the axial-gradient generator (AGG), a solenoidal coil pair arranged in Maxwell configuration. These layers form the selection field generator and can offer a rotating FFL [2], while the latter one is sufficient to create an FFP. Separated by a 2 mm thick cylindrical copper shield, each of the inner two layers contains a curved coil pair in Helmholtz configuration to generate the drive field (DF). The DF can be oriented in arbitrary radial direction by linear combination of the magnetic fields of both coil pairs of the DF generator. In this work, the selection field is chosen to provide an FFP. For that, the AGG operates with a DC current 751 A to generate a radial field gradient of 0.4 T/m in direction. For the DF, the inner coil pair is fed with an RMS current of 110 A at a frequency of 25.25 kHz and the current for the outer coil pair amounts to 142 A at a frequency of 24.75 kHz. Hence, the DF amplitude

Figure 1: 2D receive coil consisting of tilted solenoids with drive-field-compensating coils.

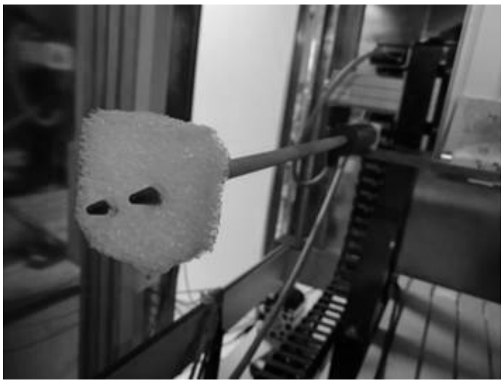

Figure 2: 2-dot phantom with 2 different amounts of Resovist samples with a distance of 12 mm between the edges apart.

is 8 mT in horizontal as well as in vertical direction and therefore, a square FOV with an edge length of 40 mm can be fully covered by the FFP.

II.II Receive coil

To pick up the particle signal, a receive coil arrangement was specifically tailored for this field generator. It is based on tilted solenoids to form an electromagnetic dipole in radial direction [3] and holds compensation windings to cancel out the receive signal in the absence of a particle sample within the FOV (see Fig. 1). With an inner diameter of 80 mm, it covers the whole FOV.

II.III Measurement setup and data acquisition

First measurements were performed with one DF component only to obtain 1D images moving the FFP on a vertical line. A SM was recorded by moving a delta

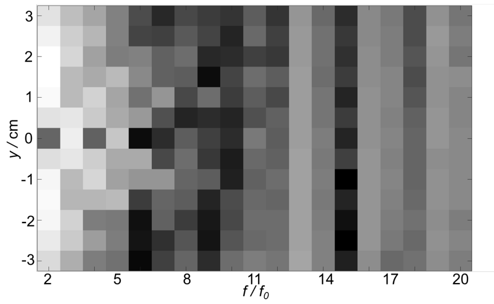

Figure 3: 1D SM. Each column stands for a harmonic of the base frequency $f_0 = 25.25$kHz, the rows represent the position in the FOV with $y = 0$cm being the center of the scanner.

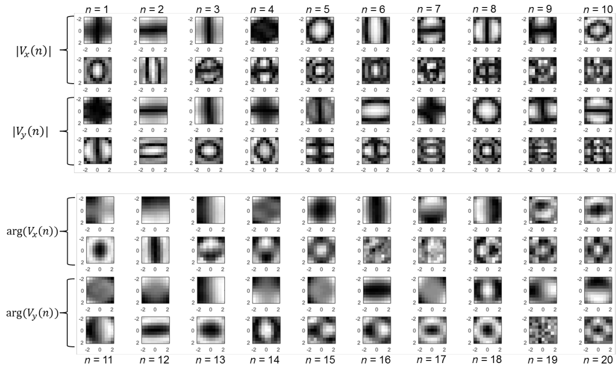

Figure 4: 2D system matrix. The top half of the picture shows the amplitude spectra of both channels for 20 different frequency components. The bottom half shows the according phase spectra.

sample with 100 μL undiluted Resovist along a grid with 13 positions with a distance of 5 mm between each other covering a FOV with a length of 6 cm. The empty spectrum was subtracted. A second measurement was performed using the entire DF generator steering the FFP along a Lissajous trajectory. A SM on a grid of 9x9 positions within a FOV of 4x4 cm^2 was recorded. Using algebraic reconstruction technique (ART) with manually chosen frequency components, the particle distribution of a 2-dot phantom (Fig. 2) was reconstructed. One vessel contains 80 μL of undiluted Resovist and the other one 100 μL. The center of the vessel with the smaller amount is located $\Delta y = 5$ mm higher and $\Delta x = 15$ mm apart from the center of the other vessel.

III Results

In the following, the system matrices for the 1D- and the 2D measurements are presented. For the 2D measurements, the reconstruction of a 2-dot-phantom is shown.

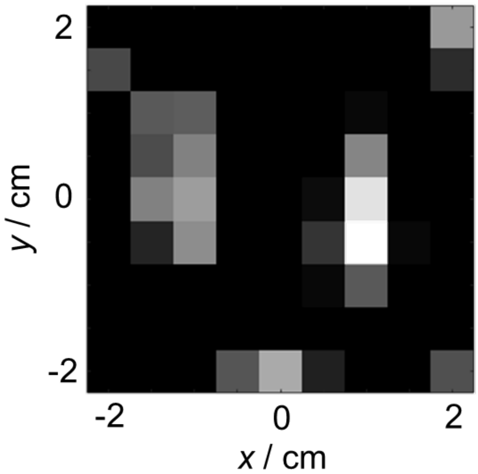

Figure 5: 2-dot phantom reconstruction. The locations as well as the different concentrations of the particle suspensions are easily distinguishable within the 4x4 cm^2 FOV.

III.I 1D system matrix

The result of the 1D measurement is depicted in Fig. 3. The visualization of the SM reveals the expected properties [4] as the odd harmonics exhibit their maximum amplitude in the center of the FOV. The even harmonics on the other hand show a minimum at the center of the FOV. The harmonics of the amplitude spectrum furthermore display a symmetric behavior with respect to the center.

III.II 2D image reconstruction

The SM obtained with the 2D measurements is shown in Fig. 4. A manual selection of the frequency components is depicted for both channels recorded by each of the receive coil components simultaneously.

A further measurement with a duration of 40 ms is performed using the 2-dot phantom. The SM is then used to perform an image reconstruction with a regularization parameter of $\lambda = 0.5$. The result can be seen in Fig. 5.

IV Conclusion

In this work, a rabbit sized MPI scanner was used to record 1D- and 2D SMs for the first time. The system was used to generate an FFP and move it along a Lissajous trajectory to obtain particle measurement data from a 2-dot phantom. ART was applied to reconstruct the particle concentration successfully. In future, a higher signal quality is expected by applying an FFL to be able to reconstruct smaller particle concentrations and obtain higher spatial resolution.

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Author's Statement

The authors state no conflict of interest.

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