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Matthias Weber*, Klaas Bente, Anselm von Gladiss, Matthias Graeser, and Thorsten M. Buzug

Sequences for real-time magnetic particle imaging

Abstract: Magnetic Particle Imaging (MPI) is a new imaging modality with the potential to be a new medical tool for angiographic diagnostics. It is capable of visualizing the spatial distribution of super-paramagnetic nanoparticles in high temporal and spatial resolution. Furthermore, the new spatial encoding scheme of a field free line (FFL) promises a ten-fold higher sensitivity. So far, all know imaging devices featuring this new technique feature slow data acquisition and thus, are far away from real-time imaging capability. An actual real-time approach requires a complex field generator and an application of currents with very precise amplitude and phase. Here, we present the first implementation and calibration of a dynamic FFL field sequence enabling the acquisition of 50 MPI images per second in a mouse sized scanner.

Keywords: MPI; FFL; magnetic nanoparticles; real-time imaging

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1 Introduction

Two spatial encoding schemes have been investigated for the new imaging modality MPI [1]. One is based on a field free point (FFP) and one on a FFL. FFL imaging promises a ten-fold higher sensitivity [2], but could not be realized for real-time data acquisition yet. Furthermore, optimized reconstruction methods could be utilized to reconstruct the acquired data online [3]. It has been previously shown that an electrically, but still discrete, rotation of a FFL might have the potential to be suited for this scenario [4–7]. Based on this work, a realization of a dynamic trajectory for real-time FFL-MPI is investigated and verified with a preliminary phantom measurement. The system acquires 50 two-dimensional frames per second.

***Corresponding Author: Matthias Weber:** Universität zu Lüebeck, Institute of Medical Engineering, Ratzeburger Allee 160, 23562 Lüebeck, E-mail: weber@imt.uni-luebeck.de
Klaas Bente, Anselm von Gladiss, Matthias Graeser, Thorsten M. Buzug: Universität zu Lüebeck, Institute of Medical Engineering, Ratzeburger Allee 160, 23562 Lüebeck, E-mail: bente@imt.uni-luebeck.de, gladiss@imt.uni-luebeck.de, graeser@imt.uni-luebeck.de, buzug@imt.uni-luebeck.de

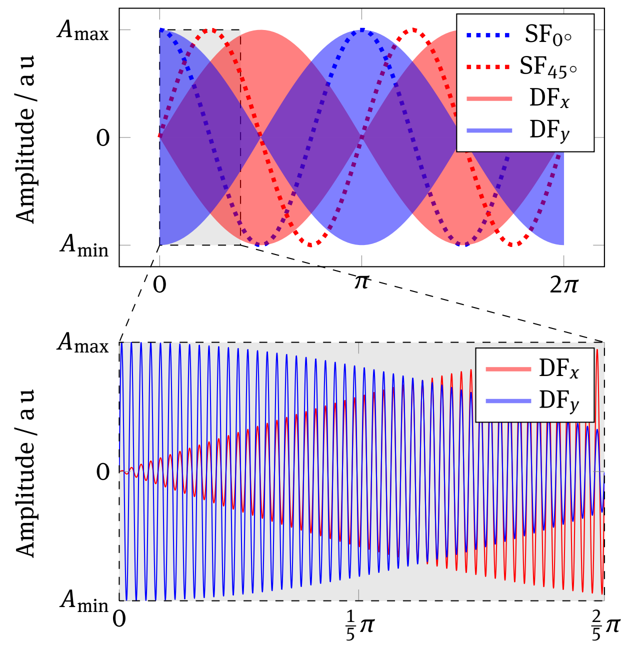

Figure 1: The upper plot shows the shape of the currents being needed to initialize a dynamical radial FFL trajectory for a rotation of 360°. The lower plot shows a magnified extract where the excitation signal can be resolved. Here, an excitation signal of 25 kHz is utilized.

2 Methods

The utilized approach to enable a dynamic radial trajectory is based on a rotating gradient field featuring a FFL with a rotation frequency of f_{rot} = 50 Hz. This field is generated by two quadropoles (SF_0 and SF_{45}). The FFL is shifted orthogonally in relation to its extension with a frequency of f_{trans} = 25 kHz. This is achieved by two perpendicular aligned Helmholtz coil pairs (DF_x and DF_y). Four independent sending channels are needed for this scenario. The shape of the signals is defined as follows

$$SF_{0^\circ} = \sin\left(2\pi \cdot 2f_{rot} \cdot t + \pi/2\right) \quad (1)$$
$$SF_{45^\circ} = \sin\left(2\pi \cdot 2f_{rot} \cdot t\right) \quad (2)$$
$$DF_x = \sin\left(2\pi \cdot f_{trans} \cdot t\right) \cdot \sin\left(2\pi \cdot f_{rot} \cdot t\right) \quad (3)$$
$$DF_y = \sin\left(2\pi \cdot f_{trans} \cdot t\right) \cdot \sin\left(2\pi \cdot f_{rot} \cdot t + \pi/2\right) \quad (4)$$

The desired currents for the named trajectory are shown in Fig. 1 which indicates a FFL rotation of 360°. This sequence is calibrated with a feedback loop by measuring the voltages over the field generating coils and compensat-

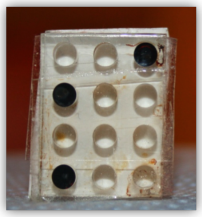

Figure 2: Constructed delta sample phantom. The phantom contains three delta samples filled with undiluted Resovist®. Each sample has a diameter of 2 mm. The distance of the samples is approximately 12 mm.

ing for any phase and amplitude differences caused by the system itself.

Furthermore, to evaluate if the applied field sequences are suitable for imaging and if the minimized phase and amplitude differences do not result in artifacts, a simple phantom measurement is utilized. A simple phantom with three delta samples is filled with undiluted Resovist® and pulled two times through the the FOV during image acquisition. The phantom is shown in Fig. 2. During data acquisiton, the phantom was moved through the imaging plane twice.

3 Results

The utilized feedback loop minimizes phase and amplitude differences between the sending coils. This is confirmed by measuring the delta sample phantom from Fig. 2. The reconstructed data is shown in Fig. 3. The single samples can clearly be resolved. Furthermore, one can identify that the particle distribution appears twice which correlates with the movement of the phantom.

4 Conclusion

Ensuring a dynamic trajectory for FFL-MPI is the basis for real-time data acquisition and enables reconstruction of 50 frames per second with the proposed scanner design. Therefore, the utilized method minimizes amplitude and phase errors. The preliminary phantom measurements confirm great agreement. For future work, more complex phantoms have to be analyzed and additionally, an implementation of a online reconstruction could directly monitor the actual particle distribution. Furthermore, flow measurements are possible with the presented imaging device.

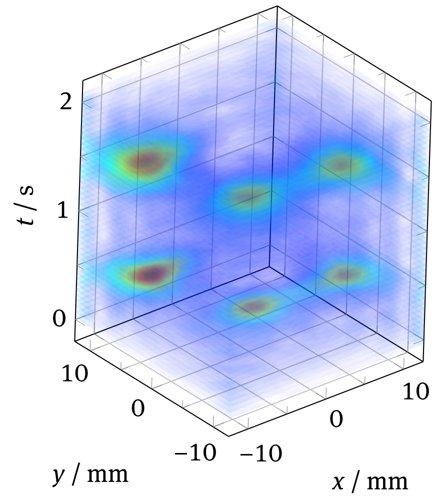

Figure 3: The plot shows the reconstructed particle signal on the two-dimensional imaging region x/y ($25 \times 25\ mm^2$) over a time period of 2 s. During imaging time, a phantom with three delta samples of undiluted Resovist® (see Fig. 2) passed the imaging slice twice. These time points, as well as the delta samples, are clearly identifiable in the plot.

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Author's Statement

Conflict of interest: Authors state no conflict of interest. Material and Methods: Informed consent: Informed consent has been obtained from all individuals included in this study. Ethical approval: The research related to human use has been complied with all the relevant national regulations, institutional policies and in accordance the tenets of the Helsinki Declaration, and has been approved by the authors' institutional review board or equivalent committee.

References

[1] B. Gleich and J. Weizenecker, "Tomographic imaging using the nonlinear response of magnetic particles." *Nature*, vol. 435, no. 7046, pp. 1214–1217, Jun 2005.

[2] J. Weizenecker, B. Gleich, and J. Borgert, “Magnetic particle imaging using a field free line,” *Journal Of Physics D: Applied Physics*, vol. 41, no. 10, p. 105009, 2008.

[3] T. Knopp, M. Erbe, T. F. Sattel, S. Biederer, and T. M. Buzug, “A fourier slice theorem for magnetic particle imaging using a field-free line,” *Inverse Problems*, vol. 27, no. 9, p. 095004, 2011.

[4] M. Erbe, M. Weber, T. F. Sattel, and T. M. Buzug, “Experimental validation of an assembly of optimized curved rectangular coils for the use in dynamic field free line magnetic particle imaging,” *Current Medical Imaging Reviews*, vol. 9, no. 2, pp. 89–95, 2013.

[5] M. Weber, M. Erbe, K. Bente, T. F. Sattel, and T. M. Buzug, “Scanner construction for a dynamic field free line in magnetic particle imaging,” in *BMT 2013*, Sep 2013.

[6] M. Weber, K. Bente, and T. M. Buzug, “Insight in scanner construction for a dynamical field free line for magnetic particle imaging,” in *BMT 2014*, Oct 2014.

[7] K. Bente, M. Weber, M. Graeeser, T. F. Sattel, M. Erbe, and T. M. Buzug, “Electronic field free line rotation and relaxation deconvolution in magnetic particle imaging,” *IEEE Trans Med Imaging*, 2014.