International Journal on Magnetic Particle Imaging
Vol 11, No 1, Suppl 1, Article ID 2503026, 3 Pages

Proceedings Article

Simulation of Multi-Coil Single-Sided MPI System with Offset Field Spatial Encoding

Qibin Wang[a,*] · Kaixiong Yang[a] · Linwen Hou[a] · Yihan Wang[a] · Franziska Schrank[b,c] · Harald Radermacher[b,c] · Volkmar Schulz[b,c,d] · Shouping Zhu[a,*]

[a]School of Life Science and Technology, Xidian University & Engineering Research Center of Molecular and Neuro Imaging, Ministry of Education, Xi'an, Shaanxi 710126, China
[b]Institute for Experimental Molecular Imaging, RWTH Aachen University, Aachen, Germany
[c]Institute of Imaging and Computer Vision, RWTH Aachen University, 52074 Aachen, Germany
[d]Fraunhofer Institute for Digital Medicine MEVIS, Aachen, Germany
[*]Corresponding author, email: volkmar.schulz@lfb.rwth-aachen.de, spzhu@xidian.edu.cn

Abstract

Single-sided magnetic particle imaging (MPI) systems have great potential for clinical applications because they concentrate all hardware on one side, allowing for an unrestricted imaging volume. However, the non-uniform magnetic field distribution in single-sided MPI devices poses challenges for generating high gradient selection fields. To address this, we developed a new offset field spatial encoding technique that combines amplitude modulation technology within a multi-coil structure, enabling 3D imaging without the need for classical selection fields and mechanical movement scanning. In simulation experiments, we validated the feasibility of this design, and the results indicate that the single-sided MPI device based on multi-coil amplitude modulation technology has the potential to achieve high spatial resolution and high temporal resolution.

I. Introduction

Single-sided MPI devices have the potential for direct clinical application. All its hardware is concentrated on one side of the system, eliminating scanning size limitations [1,2]. However, this structure has noticeable performance compromises. It faces limitations in detection depth and challenges in generating high gradients of the selection field due to the non-uniform field distribution [1,2]. To address these issues, a novel method of offset field spatial encoding was introduced in our previous work [3]. However, previous studies still rely on mechanical movement, which limits their application. To overcome this challenge, we have innovatively proposed a new structure that employs a multi-coil configuration to change the spatial position of the excitation magnetic field, combined with amplitude modulation technology to further optimize the control of the magnetic field's movement. The proposed method enables rapid 3D reconstruction without the need for a classical selection field or mechanical movement scanning, and its feasibility for 2D reconstruction has been validated through simulation experiments.

II. Methods and materials

II.I. MPI system hardware

The single-sided device designed in this study mainly consists of seven small-diameter excitation coils, an offset coil, a receiving coil at the bottom, and a compensating coil at the top. The structure of the device is illustrated in Figure 1.

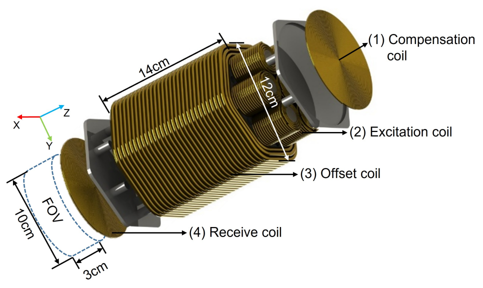

Figure 1: Schematic diagram of device hardware composition.

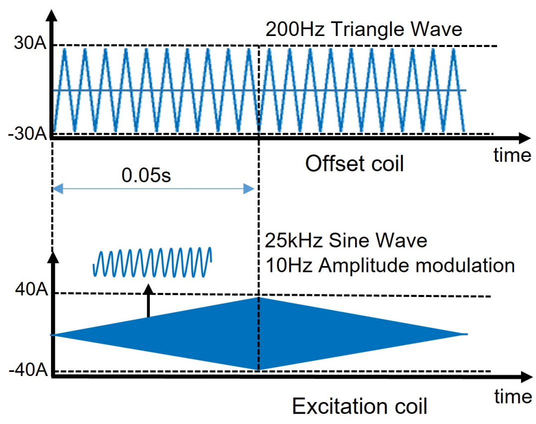

Figure 2: Excitation and offset current timing diagram.

II.II. Simulation procedure

The device designed in this paper uses multiple coils driven by an alternating power supply to achieve the movement of the magnetic field in space. When performing permutations and combinations without considering the order of the excitation coils, there are a total of $N = 127$ power switchings. The excitation coils operate at an alternating current frequency of 25 kHz and an amplitude modulation frequency of 10 Hz, with a peak current of 40 A. A 200 Hz triangular wave current with a peak of 30 A is introduced into the offset coil to encode spatial positions. At this point, a 3D scan takes at least 6.35 seconds.

The reconstructed FOV is a 3D cylinder with a radius of $r = 50$ mm and a height of $h = 30$ mm. To verify this method's feasibility, we conducted a simulation experiment using 2D reconstruction. We created models of the excitation and offset coils in COMSOL, then imported the magnetic field data into MATLAB to simulate magnetic particle signals. By establishing a system matrix, we employed the regularized Kaczmarz algorithm [4] for image reconstruction, with a total of 200 iterations.

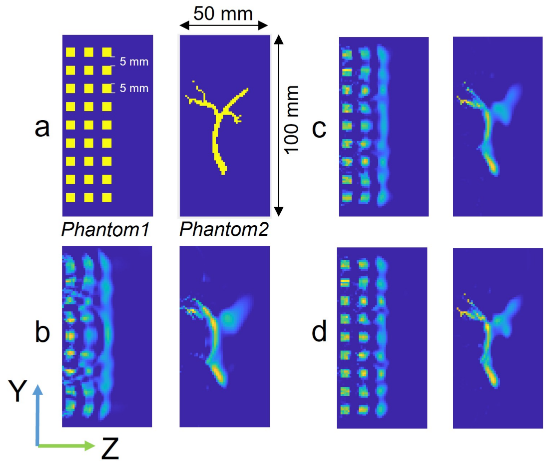

Figure 3: a) Two phantoms. b) Result without amplitude modulation. c) Amplitude-modulated 3^{rd} harmonic reconstruction. d) Amplitude-modulated multi-harmonic reconstruction.

III. Results and discussion

The simulation experiments were conducted on two different phantoms, as shown in Figure 3a. Initially, a reconstruction experiment was conducted without amplitude modulation, and the results are shown in Figure 3b. Subsequently, we applied amplitude modulation to each excitation coil, using the 3^{rd} harmonic for reconstruction, the results are presented in Figure 3c. Finally, under the amplitude modulation strategy, we performed joint reconstruction using multiple harmonics (3^{rd}, 5^{th}, and 7^{th}) [3], and the results are shown in Figure 3d. None of the simulation experiments considered the effects of noise. The experimental results indicate that employing the amplitude modulation strategy with the excitation coils can significantly enhance the quality of the reconstructed images. When noise levels are not taken into account, the use of multi-harmonic signals for reconstruction further enhances the quality of the reconstructed images.

IV. Conclusions

This study presents a novel multi-coil single-sided MPI structure that utilizes amplitude modulation and offset field spatial encoding technology. It enables 3D reconstruction of magnetic nanoparticle concentration distribution without the need for classical selection fields or mechanical scanning, thereby enhancing spatial resolution and reducing scanning time. Simulation experiments have validated the feasibility of this method, demonstrating its potential value for future clinical applications in the imaging of superficial tissues within the human body.

Acknowledgments

This work was supported by the National Natural Science Foundation of China under Grant Nos. 62027901, 62071362, 82272050, 61901342, the National Key Research and Development Program of China under Grant No. 2022YFB3203803, the Natural Science Ba-sic Research Program of Shaanxi Province under Grant Nos. 2021JZ-29, 2021SF-131, 2021SF-169.

Author's statement

Conflict of interest: Authors state no conflict of interest.

References

[1] Gräfe K, von Gladiss A, Bringout G, et al. *2D images recorded with a single-sided magnetic particle imaging scanner*, IEEE transactions on medical imaging, 2015, 35(4): 1056-1065.

[2] McDonough C, Chrisekos J, Tonyushkin A. *Tomographic Magnetic Particle Imaging with a Single-Sided Field-Free Line Scanner*, IEEE Transactions on Biomedical Engineering, 2024.

[3] Q. Wang *et al.*, *Single-sided Magnetic Particle Imaging Device with Offset Field based Spatial Encoding*, in IEEE Transactions on Medical Imaging, doi: 10.1109/TMI.2024.3522979.

[4] P. C. Hansen and D. P. O'Leary, *The Use of the L-Curve in the Regularization of Discrete Ill-Posed Problems*, SIAM Journal on Scientific Computing, vol. 14, no. 6, pp. 1487–1503, Dec. 1993.

10.18416/ijmpi.2025.2503026