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System function analysis of MPI with Field-Free Line and excitation coil configurations

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Abstract

Magnetic Particle Imaging (MPI) visualizes magnetic particle distributions using their nonlinear magnetization response. This study compares the performance of Coaxial (Co-Config) and Orthogonal (Ortho-Config) coil arrangements in an MPI system with Field-Free Line (FFL) scanning. Co-Config aligns the excitation field coaxially with the FFL, while Ortho-Config aligns it orthogonally. System functions were evaluated along the X-axis to analyze phase alignment and sensitivity. Ortho-Config exhibited anti-phase components caused by the interaction between the FFL and the excitation field, reducing detection sensitivity compared to Co-Config, which showed consistent phase alignment. Co-Config demonstrated higher sensitivity, making it more suitable for practical applications.

I. Introduction

Magnetic Particle Imaging (MPI) visualizes particle distributions using the nonlinear magnetization of magnetic particles [1]. The Field-Free Line (FFL) method improves MPI sensitivity by scanning the Field of View (FOV) [2-3]. We developed a compact MPI system for small animals using an FFL generated by permanent magnets and iron yokes [4-5]. This study compares two configurations: Coaxial (Co-Config), with the excitation field aligned to the FFL, and Orthogonal (Ortho-Config), with the field applied perpendicular to the FFL. We experimentally investigated how the interaction between the FFL and the excitation field affects sensitivity distribution in both configurations.

II. Methods and materials

The magnetic field $\mathbf{H_G} = (-Gx,\ Gy,\ 0)$ and alternating excitation field $\mathbf{H_{drive}}$ are superimposed to generate a magnetization response. To compare the system functions of Co-Config and Ortho-Config, we measured the signal response for each setup using a Resovist® sample (Fujifilm RI Pharma) sealed in a 2 mm diameter, 0.025 mL cylindrical container. Fig. 1 shows the configuration of the MPI system with FFL used in the experiment. In the Co-Config, the excitation field is applied along the Z-axis, parallel to the FFL. The alternating field is given by $\mathbf{H_{drive}} = (0,\ 0,\ A\cos\omega\ t)$, where A is the amplitude and ω the angular frequency. The composite field is:

$$\mathbf{H}^{\mathbf{Co}}_{\mathbf{total}} = \mathbf{H_{drive}} + \mathbf{H_G} = \begin{bmatrix} -Gx \\ Gy \\ A\cos\omega t \end{bmatrix}. \tag{1}$$

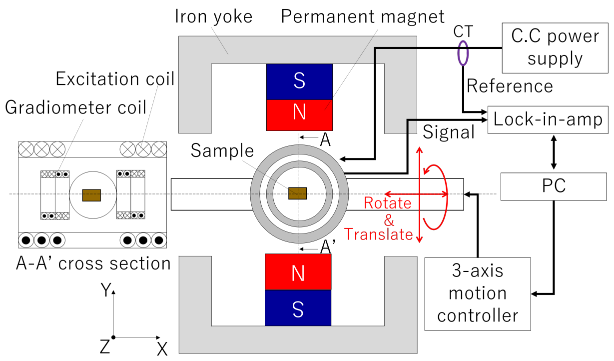

Figure 1: Schematics of FFL-MPI Configuration: Co-Config with the excitation field parallel to the FFL (Z-axis).

This configuration avoids interaction between the FFL and the excitation field, enabling stable signal acquisition. In contrast, the Ortho-Config requires the excitation field to be applied along the X-axis, which necessitates modifications to the coil arrangement shown in Fig. 1. In this configuration, the alternating field is expressed as $\mathbf{H}_{\mathbf{drive}} = (A\cos\omega t,\ 0,\ 0)$. The composite field becomes:

$$\mathbf{H}_{\mathbf{total}}^{\mathbf{Ortho}} = \mathbf{H}_{\mathbf{drive}} + \mathbf{H}_{\mathbf{G}} = \begin{bmatrix} A\cos\omega t - Gx \\ Gy \\ 0 \end{bmatrix}. \quad (2)$$

The Ortho-Config poses a challenge due to interaction between the FFL and the excitation field, causing phase inversion in the sensitivity distribution. This leads to anti-phase components at specific positions, reducing signal sensitivity, especially for widely distributed particles. System functions were measured along the X-axis, with continuous scanning to ensure precise data acquisition. A lock-in amplifier synchronized to the excitation field's reference frequency was used to extract harmonic amplitude and phase for detailed analysis [4-5].

III. Results and discussion

Fig. 2 shows the results of scanning the sample along the X-axis under the following conditions: excitation frequency of 500 Hz, field amplitude of 19 mT, and gradient field strengths of 1 and 2 T/m. With the Co-Config, all signals were detected in-phase. In contrast, the Ortho-Config showed anti-phase components on both sides of the 0 mm position due to interaction between the FFL and the alternating excitation field, suggesting partial signal cancellation and a potential reduction in sensitivity, especially for widely distributed particles. The Co-Config, with the excitation field aligned parallel to the FFL, maintained stable sensitivity and ensured high detection sensitivity for widely distributed particles, making it highly suitable for practical MPI applications.

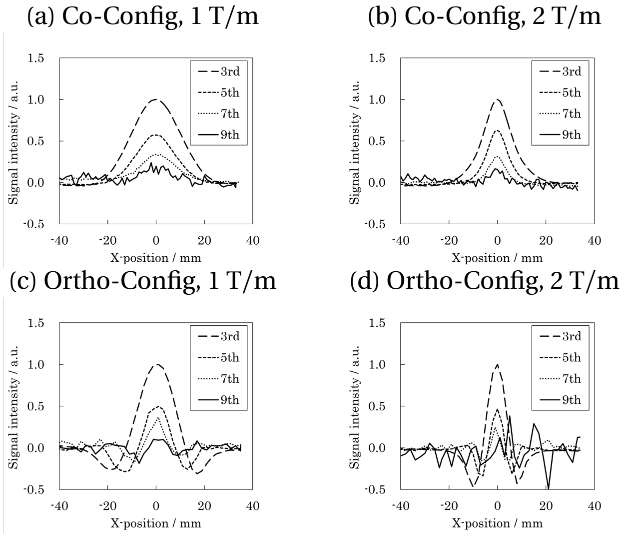

Figure 2: One-dimensional system function evaluation. Signal intensity is normalized to the maximum value of 3rd harmonic signal.

IV. Conclusions

This study compared the system functions of the Co-Config and Ortho-Config in MPI using the FFL method, revealing the impact of the interaction between the alternating excitation field and the FFL on system performance. The Co-Config demonstrated high phase alignment and was well-suited for measuring particles over a wide area. In contrast, the Ortho-Config faced challenges due to sensitivity reduction caused by phase inversion. Future research will focus on optimizing the system functions of the Co-Config through frequency adjustments and further improvements in coil arrangements.

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Author's statement

Conflict of interest: Authors state no conflict of interest. Informed consent: Informed consent has been obtained from all individuals included in this study.

References

[1] B. Gleich and J. Weizenecker, *Tomographic imaging using the nonlinear response of magnetic particles,* Nature, vol. 435, pp. 1214–1217, 2005.

[2] J. Weizenecker, B. Gleich, et al., *Magnetic particle imaging using a field free line*, J. Phys., D41:105009, 2009.

[3] T. Knopp, M. Erbe, S. Biederer, T. F. Sattel, and T. M. Buzug, *Efficient generation of a magnetic field-free line*, Med. Phys., vol. 37, pp. 3538, 2010.

[4] M. Washino, K. Nomura, K. Yamauchi, T. Matsuda, Y. Susumu, S. Seino, T. Nakagawa, T. Sakane, T. Kiwa and S. Tonooka, *Magnetic signal evaluation and imaging of magnetic nanoparticles in brain phantom*, Int. J. Mag. Part. Imag., vol. 8, no. 1, Suppl. 1, Mar. 2022.

[5] K. Nomura, M. Washino, T. Matsuda, S. Tonooka, S. Seino, H. Yoshida, K. Nishigaki, T. Nakagawa, and T. Kiwa, *Magnetic-Particle-Discrimination Method Using Difference of Relaxation Time for Magnetic Particle Imaging*, IEEE Magn. Lett., vol. 14, pp. 8100105, 2023.

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