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Optimized Single-Channel Head Coil for Maximizing Drive Field Amplitude Within Safety Limits: A Simulation Study

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Abstract

This study investigates the design of an optimized single-channel head coil to maximize drive field (DF) amplitudes while minimizing the risk of peripheral nerve stimulation (PNS) in the human head. Using an optimization algorithm, we select the optimal winding positions on a fixed-length coil and achieve up to 25% increase in DF amplitude for superior portions of the head. Future work will analyze coil parameters and the choice of optimization constraints to increase DF amplitudes within the safety limits, across the entire human head.

I. Introduction

Magnetic Particle Imaging (MPI) utilizes time-varying magnetic fields called drive fields (DFs) to excite the magnetic nanoparticles (MNPs) for imaging. Time-varying magnetic fields induce electric fields (E-fields) within the human body, which can result in peripheral nerve stimulation (PNS) above a certain threshold [1–3].

Previously, we presented a simulation study on optimizing current amplitudes for a head-size drive array coil [4]. While that approach effectively reduced the induced E-fields to safer levels when compared to those from a standard solenoid coil, it came with the drawback of increased hardware complexity. In this study, we propose a practical single-channel head coil design to reduce the induced E-fields. The proposed approach determines the optimal winding positions for a single-channel head coil design to maximize the DF amplitude and maintain the DF homogeneity for a region of interest (ROI), while remaining within the safety limits.

II. Materials and Methods

The proposed coil design builds upon our earlier magnetostimulation coil featuring a 28 cm coil length, 30 cm diameter, and 13 turns [5]. Assuming a 1 cm rectangular-cross section for each winding, we first fix 28 potential positions and aim to determine the winding positions that provide the optimal magnetic field distribution while minimizing the induced E-fields to prevent PNS.

Here, the target DF amplitude was set to 5 mT along the z-direction based on previous human-subject experiments [6, 7]. We chose 0.5 T m^{-1} for selection field gradient strength, corresponding to a DF field-of-view (FOV) of about 2 cm along the z-direction. Across this ROI, a minimum DF homogeneity of 90% was set as target.

The objective was to identify the optimal positions for 13 windings to maximize the DF amplitude within the ROI, constrained by:

1. **DF Homogeneity**; Ensuring at least 90% homogeneity across the ROI.

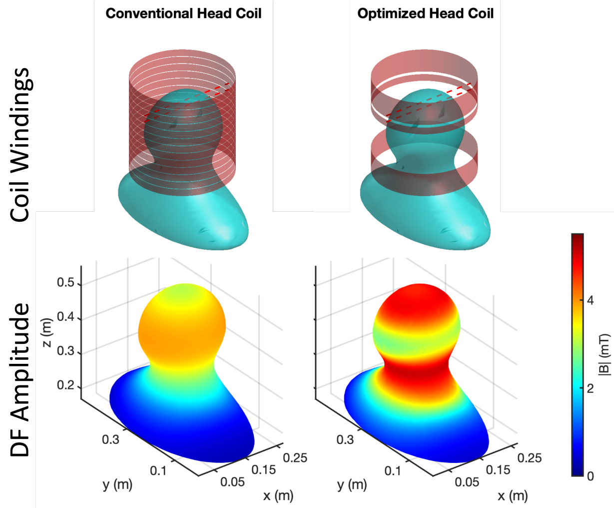

Figure 1: Comparison of [Left] conventional vs. [Right] optimized head coil winding configurations and the corresponding DF amplitudes. In this case, a 2-cm thick ROI in the superior portion of the head was chosen, for which the DF amplitude was increased by more than 25% with the optimized design, while remaining within the safety limits.

2. **E-Field Minimization**; Keeping the induced E-field safely below the PNS thresholds for the head [4].

To identify the optimal winding positions, we utilized the built-in genetic algorithm of MATLAB. This algorithm is particularly suitable for binary decision problems, enabling each of the 28 positions to be selected/unselected as winding positions.

Human-subject experiments on our conventional head-size DF coil had resulted in a PNS threshold of 4.2 mT DF amplitude at 24 kHz DF frequency [6]. For induced E-field minimization, we performed electromagnetic simulations considering the design of this coil together with a body model. This body model, simplified by neglecting sharp changes in the human anatomy, served as a practical representation for simulation purposes [8]. We calculated the corresponding maximum E-field amplitude as 36.5 V/m for the experimental PNS threshold. We set this value as the E-field PNS threshold for the abovementioned algorithm.

III. Results and Discussion

In ROIs near the superior regions of the head or the neck, the proposed algorithm achieves up to 25% increase in DF amplitude (from 4.2 mT up to 5.3 mT) (see Fig. 1) while remaining within the E-field PNS thresholds.

As seen in Fig. 1, the optimal winding positions concentrated towards the edges of the coil. This configuration maintained DF homogeneity within the ROI, while minimizing the E-field in regions with larger anatomic radius, which in turn reduced the risk of PNS. While the DF amplitude could be increased without causing PNS for ROIs near the superior regions of the head or around the neck, no significant increase could be achieved in the central regions around the nose area, where the radius of the head model was the largest. For these regions, the coil parameters may need to be changed or the constraints of optimization (e.g., the homogeneity constraint) may need to be relaxed.

IV. Conclusions

This study presents the preliminary findings in single-channel head coil optimization to maximize the DF amplitude for safe human head-size MPI. The proposed optimization approach shows promising results for increasing the DF amplitude in specific regions within the head, such as the superior region and the neck, without exceeding the safety limits.

Author's statement

Conflict of interest: Authors state no conflict of interest.

References

[1] E. U. Saritas, P. W. Goodwill, G. Z. Zhang, and S. M. Conolly. Magnetostimulation limits in magnetic particle imaging. *IEEE Transactions on Medical Imaging*, 32(9):1600–1610, 2013, doi:10.1109/TMI.2013.2260764.

[2] I. Schmale, B. Gleich, J. Schmidt, J. Rahmer, C. Bontus, R. Eckart, B. David, M. Heinrich, O. Mende, O. Woywode, J. Jokram, and J. Borgert, Human pns and sar study in the frequency range from 24 to 162 khz, in *2013 International Workshop on Magnetic Particle Imaging (IWMPI)*, 1–1, 2013. doi:10.1109/IWMPI.2013.6528346.

[3] I. Schmale, B. Gleich, J. Rahmer, C. Bontus, J. Schmidt, and J. Borgert. Mpi safety in the view of mri safety standards. *IEEE Transactions on Magnetics*, 51(2):1–4, 2015, doi:10.1109/TMAG.2014.2322940.

[4] A. A. Ozaslan, R. Babaloo, E. Atalar, and E. U. Saritas. Minimizing induced electric fields in human head-size mpi systems. *International Journal on Magnetic Particle Imaging IJMPI*, 10(1 Suppl 1), 2024.

[5] A. A. Ozaslan, A. R. Cagil, M. Graeser, T. Knopp, and E. U. Saritas. Design of a magnetostimulation head coil with rutherford cable winding. *International Journal on Magnetic Particle Imaging IJMPI*, 6(2 Suppl 1), 2020.

[6] A. A. Ozaslan, M. Utkur, U. Canpolat, M. A. Tuncer, K. K. Oguz, and E. U. Saritas. Pns limits for human head-size mpi systems: Preliminary results. *International Journal on Magnetic Particle Imaging IJMPI*, 8(1 Suppl 1), 2022.

[7] A. C. Barksdale, N. G. Ferris, E. Mattingly, M. Śliwiak, B. Guerin, L. L. Wald, M. Davids, and V. Klein. Measurement of peripheral nerve magnetostimulation thresholds of a head solenoid coil between 200 hz and 88.1 khz, 2024, doi:10.21203/rs.3.rs-4864083/v1.

[8] P. B. Roemer, T. Wade, A. Alejski, C. A. McKenzie, and B. K. Rutt. Electric field calculation and peripheral nerve stimulation prediction for head and body gradient coils. *Magnetic Resonance in Medicine*, 86(4):2301–2315, 2021, doi:https://doi.org/10.1002/mrm.28853.

