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Extending tuning coil loading for improved passive compensation in multi-frequency MPI towards nominal field strength operation

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Abstract

In Magnetic Particle Imaging (MPI), minimizing the feedthrough of the excitation signal into the receive signal helps in capturing the fundamental frequency response of the superparamagnetic iron oxide nanoparticle (SPIONs), improving the signal-to-noise ratio and assisting quantitative measurements. The concept of tuning coils can improve the performance of gradiometer receive coils by inducing suitable signals into the receive coils to reduce the remaining excitation signal without hampering the reception of the particle signal. Adjusting the current in the tuning coils is done by applying loading, controlled via solid state switches. In this work, an arrangement capable for operation at nominal field strength of a multi-frequency MPI (mf-MPI) scanner for mouse sized objects is presented. A high voltage loading board is applied. The adjustment of the load is integrated into an automated control loop.

I. Introduction

Magnetic particle imaging, a novel imaging modality invented by [1] is based on driving SPIONs into saturation and capturing their emitted signals. The excitation magnetic field is generated by feeding current into an excitation coil, typically surrounding the field of view, comprising the particle distribution. To capture the weak signal emitted by the SPIONs, the receive coil has to be placed close by, hence also within the exaction field, leading to the excitation feedthrough signal. Depending on the waveform and frequency of the excitation signal, different methods can be applied to minimize the negative impact of this feedthrough. In multi-frequency MPI (mf-MPI), meaning a variation of the excitation frequency, a first step is a gradiometer receive coil. Adding mechanical degrees of freedom helps to optimize its performance [2]. For further optimization, tuning coils (TCs) have been introduced in previous work [3], however limited to very low field strength.

In this work, steps towards an MPI scanner with gradiometer receive coil and TCs, capable of operation at nominal field strength, are presented. The compliance voltage level of the circuitry for controlled loading of the TCs is to be increased. Furthermore, limitations in drive voltage of the power amplifier for the excitation coil have to be overcome.

II. Methods and materials

The scanner setup in Fig. 1 features a receive gradiometer inside, consisting of receive coil (RC) and two compensation coils ($CC_{1,2}$), a water cooled solenoid excitation coil (EC), and multiple tuning coils (TC_n) as the outer-

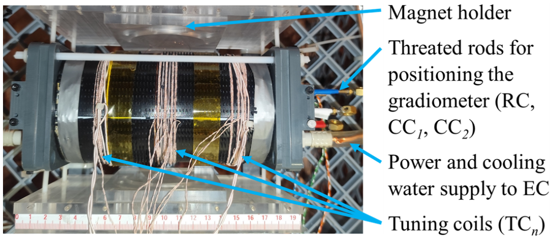

Figure 1: MPI scanner with multiple TCs wound as the outermost layer. Scale on the magnet holder is in cm.

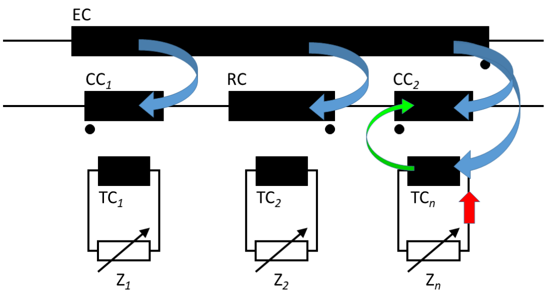

Figure 2: Principle of the tuning coils applied in the mf-MPI scanner: The large EC generates a magnetic field, inducing voltages (blue) in all exposed coils. RC and CC_n are the receive gradiometer. The load Z_n connected to the tuning coil TC_n sets the current (red) within this coil in amplitude and phase, which will induce a small voltage (green) selectively into the RC and CC, adapted from [3].

most layer. The TCs are connected to loading boards, which are linked via a microcontroller board to a PC, running the control software [4] for iteratively adjusting the loading.

Tuning coil loading, as introduced in [3], serves for inducing voltages selectively into sections of the receive gradiometer further reducing the feedthrough. As can be seen in Fig. 2, the voltage in a TC is induced by the current in the EC, hence it's frequency and phase is intrinsically linked to the excitation, which is beneficial for mf-MPI. Applying resistive or capacitive loading, the desired current in a TC is set. This alternating current will then induce a voltage predominantly into the nearby RC or CC.

The power amplifier *AE TECHRON* 7796 delivers the EC-current for generating a field strength of at least 12 mT. The voltage needs to be boosted via a series capacitor, activated when operating at >15 kHz. The EC has 26 turns, the TCs have different winding layouts with up to 12 turns. Via the coupled magnetic fields, peak voltages up to 80 V will be induced into the TCs at nominal field strength. A previous loading board was capable of withstanding only up to 15 V. Hence, a high voltage version based on solid state switches is developed. There are 16 PhotoMOS relays with a voltage rating of 100 V in a flexible switching matrix. In Fig. 3, two boards arranged

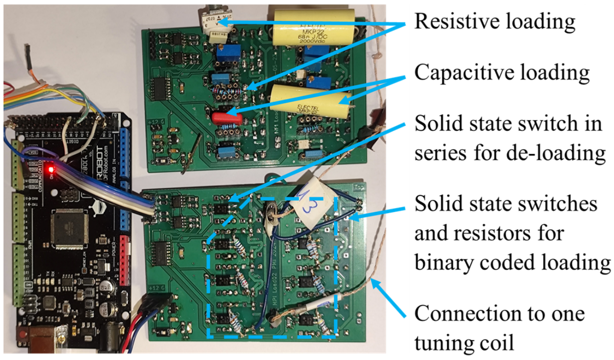

Figure 3: Microcontroller board (left) for interacting to the control PC, and high voltage loading boards (right), providing Z_n to 4 tuning coils.

to provide the controlled loading Z_n for a total of 4 TCs are shown.

III. Results and discussion

A 1D mf-MPI scanner, capable of operating with excitation fields of 12 mT throughout the frequency range of 5 to 30 kHz is realized. Tuning coils and their loading are adapted to work within this range, too. Via characterization measurements with binary coded resistor and capacitor loads, the suitable component ranges for a version with finer resolution are determined. Resulting tuning currents are <100 mA, the sensitivity profile of the scanner is altered by less than 1%. The gradiometer alone provides a feedthrough compensation of ≥60 db. As an intermediate result, this is already improved by ∼20 dB across the used frequency range.

In combination with the existing low voltage loading board - connected to several TCs with only 2 turns each to limit the voltage - we expect to boost this to > 40 dB, reaching a total feedthrough compensation of the fundamental frequency of >100 dB.

IV. Conclusion

Tuning coils for improved compensation of feedthrough can be applied to a nominal field strength mf-MPI scanner. We expect to enable capturing the fundamental frequency components of the particle signal over a wide frequency range within a fully solid state, automated system.

Acknowledgments

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Author's statement

The Authors have submitted a patent application [5] on the concept of tuning coils with selectable loading.

References

[1] Gleich, B. and J. Weizenecker (2005). *Tomographic imaging using the nonlinearresponse of magnetic particles*. In: Nature 435, pp. 1214–1217.

[2] H. Radermacher, F. Schrank, D. Pantke, F. Mueller, M. Peters, and V. Schulz, *Highly flexible gradiometer coil arrangement offering improved passive compensation for multi-frequency MPI*, International Journal on Magnetic Particle Imaging IJMPI, Vol 9 No 1 Suppl 1 (2023), doi:10.18416/IJMPI.2023.2303030.

[3] H. Radermacher, F. Schrank, D. Pantke, F. Mueller, and V. Schulz (2024). *Automated tuning coil loading for improved passive compensation for multi-frequency MPI*. In: Proc. of EMIM.

[4] D. Pantke, N. Holle, A. Mogarkar, M. Straub, and V. Schulz. *Multi-frequency magnetic particle imaging enabled by a combined passive and active drive field feed-through compensation approach*, Medical Physics, vol. 46, no. 9, pp. 4077–4086, Jul. 2019.

[5] H. Radermacher, V. Schulz, and F. Schrank, *Vorrichtung fuer die Anregung einer magnetischen oder zumindest magnetisierbaren Probe und Verfahren zur Durchgriffsreduktion*, pat., German Patent Application 102023124503.

10.18416/ijmpi.2025.2503027