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Thermal Considerations Towards a Highly Flexible Multi-Core Selection and Focus Field Generator

Eric Aderhold [a,*] · Liana Mirzojan [a,b,*] · Jan-Philipp Scheel [a,b,*] · Mandy Ahlborg [a] · Florian Sevecke [a,b] · Pascal Stagge [a] · Egor Kretov [a] · Thorsten Buzug [a,b] · Matthias Graeser [a,c]

[a] Fraunhofer IMTE, Fraunhofer Research Institution for Individualized and Cell-Based Medical Engineering, Lübeck, Germany
[b] Institute of Medical Engineering, University of Lübeck, Lübeck, Germany
[c] Chair of Measurement Technology, Universität Rostock, Rostock, Germany
[*] Corresponding author, email: {eric.aderhold;liana.mirzojan;jan-philipp.scheel}@imte.fraunhofer.de

Abstract

This paper presents interim results in the development and implementation of a selection and focus field generator for Magnetic Particle Imaging. The construction of a multi-coil field generator specifically designed for the purpose of perfusion imaging of the brain is a complex task. The degrees of freedom in topological decisions with interconnected dependencies require careful considerations. The preliminary results of the initial constructional and electrical concept based on simulations are presented. A focus in decision making was placed on the manufacturability of the coils and their thermal properties. The conducted experiments indicate that the manufacturing and fixation of the core coil module presents a significant challenge. Additionally, more advanced cooling strategies have been pre-evaluated, as the intended cooling setup has been found to be inadequate in the visualized setup.

I. Introduction

Magnetic Particle Imaging (MPI) is an innovative imaging technique that visualizes the spatial distribution of magnetic nanoparticles. A crucial component of MPI is the selection and focus field generator (SeFo). The SeFo creates a gradient field with a field free region (FFR), which enables the spacial encoding [1]. Recently a new multi-coil and -core SeFo topology was introduced [2]. This topology promises a significant gain in efficiency by utilizing the properties of soft magnetic materials. Currently, a human head size upscaled SeFo concept with a similar topology is in development [3]. The new topology offers a greater number of design options, which necessitates the consideration of certain trade-offs. These include, but are not limited to, efficiency, cost-effectiveness, manufacturability, serviceability, electric properties and Joule heating.

II. Methods and materials

The field generator, constructed for bed-side stroke monitoring, consists of $2 \times (3 \times 3)$ core coil modules (CCM) [2, 3]. Each of these CCM units comprises a soft magnetic core, onto which numerous coils are mounted. The cores utilized for this selection field generator are made from electric steel of type M800-50A. To significantly re-

duce eddy current losses it is sheeted with a thickness of 0.55 mm. Those sheets sheets are laminated, and the full core is coated with a protective lacquer layer. The material offers good post-processing capabilities and more importantly has a high saturation magnetization of ≈ 2 T, for achieving a high field strength.
The coil design is based on a power and topology optimisation focusing on a form-filling approach [3]. The current SeFo configuration anticipates the use of eight coils per CCM. The coils are wound from copper bands with a cross section of 25×0.25 mm^2 and are partially coated with polyester for insulation. As the production of a non-circular spiral coil is a challenging process, machine production of the coils was commissioned. In order to provide a convenient and adaptable interconnection, a dedicated modular interconnection unit situated behind the coils on each core is prepared. The combination of nine CCM into a magnetic field generator will be housed within a soft magnetic enclosure. This configuration is anticipated to channel magnetic flux, minimise stray fields and enhance the power efficiency of the field generator. Various methods to enhance the geometric stability of the coils within one CCM have been considered, as those were initially solely wrapped and bonded with a single layer of polyimide tape. One approach involves baking the coil layers together, while another method focuses on glueing the side surfaces of the coil. A series of thermal investigations were conducted with the aim of evaluating the thermal stability of both options. The various coils were positioned on a core for each measurement and heated by ohmic losses due to a current of 30 A. Since passive cooling from the coils to the core proved insufficient, an additional water cooling was developed. To assess the efficiency of the cooling interface, the heating of a polyimide tape-fixated coil at 30 A was compared to cooling the same coil from both sides. Additionally, the cooling of two coils in a pair with cooling from both outer sides is presented.

III. Results and discussion

For all compared coils the temperature rises with a comparable slope to $\Delta T \sim 70\,°\mathrm{C}$ within 20 min (Figure 1).

Furthermore, adding thermal interface material (TIM) between the baked coil and the core shows no significant improvement. However, a deformation of the coils, due to glass transition of the adhesive/baked layers and the resulting internal forces, occured. For this reason, both methods were abandoned and the polyimide bonding was reinforced instead. The additional cooling shows promising results in both cases. In the case of a single cooled coil, active water cooling reaches a steady state at around 15 min. Whereas with the coils arranged as a pair, a stationary state can be recognised from approx. 35 min.

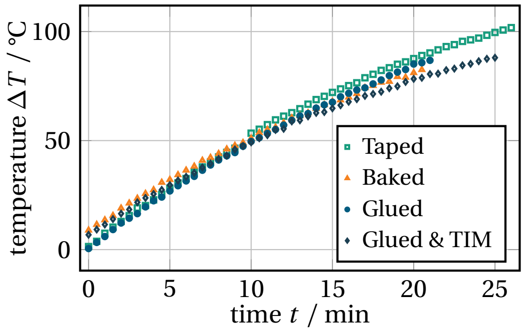

Figure 1: Temperature measurement of individual coils subjected to various post-processing treatments in relation to the ambient room temperature.

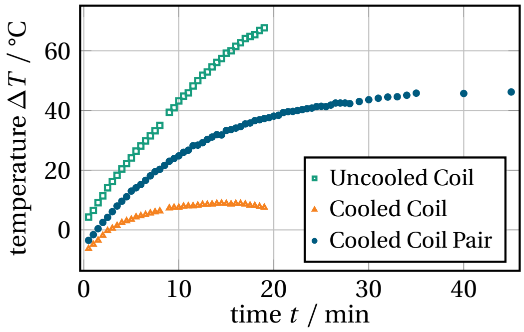

Figure 2: Temperature measurement in relation to the measured room temperature, for different cooling setups.

IV. Conclusion

The complexity of the system has shown that measurements are necessary in order to recognize and eliminate problems at an early stage. In addition, many insights were gained from the measurements and used to refine simulations. While the conducted experiments revealed challenges the project was successfully driven forward.

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Author's statement

Authors state no conflict of interest.

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