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Towards industrial production: An additive approach for magnetic particle spectrometers

Pascal Stagge [a,*] · Ankit Malhotra [a] · Justin Ackers [a] · Eric Aderhold [a] · Jan-Philipp Scheel [a] · Jonas Schumacher [a] · Florian Sevecke [a] · Mandy Ahlborg [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: pascal.stagge@imte.fraunhofer.de

Abstract

Magnetic particle spectroscopy is an innovative method for characterizing magnetic nanoparticles with potential medical applications. Traditional methods for instrumentation face challenges such as labor-intensive coil manufacturing, high costs, high tolerances and setup time. This study introduces a new approach using additive manufacturing to create rectangular nested coils, enhancing performance and reducing production complexity. The coils, printed with conductive and dielectric inks, allow for modular configurations and improved sensitivity. Results demonstrate a sufficient signal-to-noise ratio and effective cancellation of excitation frequencies. This presented technique addresses issues of fine-tuning and manufacturing discrepancies while enabling modular and flexible setups tailored to researchers' specific needs.

I. Introduction

Magnetic particle spectroscopy represents a novel approach to magnetically characterize magnetic nanoparticles (MNP). It demonstrates high potential for the characterization of MNP properties and holds promise for the preliminary assessment of medical applications [1, 2]. Over the past few years, numerous research facilities have presented different approaches to building magnetic particle spectrometers (MPS) [1]. Indispensable components of an MPS are coils to create an oscillating magnetic field, driving the MNP in saturation and inducing a distorted signal that is picked up by a dedicated receive coil. Typically, these coils are wound by hand or by a highly skilled manufacturer using a winding machine, leading to different drawbacks such as high workload, long setup times, material loss, and overall high costs. Furthermore, industrial fabrication requires a highly standardized process with minimal steps, leading to a reduction of required time and a minimized level of knowledge which demands less experience for production. This abstract describes an alternative way of fabricating coils for a spectrometer and demonstrates its functionality in a conventional 1D MPS setup paving the way to industrial manufacturability.

II. Methods and materials

The research project involved the design, simulation, manufacturing and validation of additive manufactured coils. The developed component, illustrated in Figure 1, consists of two rectangular-shaped nested coils with

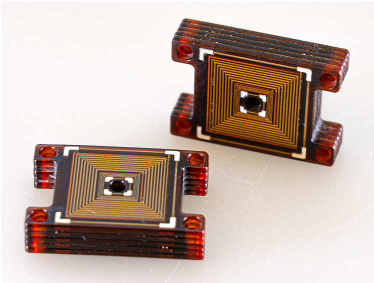

Figure 1: Additive fabricated prototype containing the nested structure of two rectangular coils.

outer dimensions of 26.18 mm x 35.63 mm x 1.43 mm and an inner bore of 3 mm. The component is constructed from conductive and dielectric ink, printed with the Dragonfly IV 3D printer by Nano Dimension. The configuration of the coils permits the stacking of multiple units to enhance the number of turns, thereby augmenting the overall performance in terms of power loss or sensitivity. Consequently, the design exhibits considerable versatility in accommodating the specific requirements of a given project. The nested configuration of both coils yields a fixed geometric relation, enabling the construction of a state-of-the-art high-damping cancellation unit [3], which suppresses the excitation frequency, and the noise produced in the system. The stack of coils is mounted to a customized printed circuit board (PCB), which enables the propagation of the sensitive receive signal to amplifying chips or filtering options. The PCB also allows to implement standardized cooling methods effortlessly. As a demonstrator a typical 1D field generator consisting of a resonant send chain at 25 kHz and a receive chain is fabricated. Regular stock components were added to complete a setup of a conventional 1D MPS [1].

III. Results and discussion

The 3 mm bore was loaded with an undiluted sample (Perimag, micromod, Rostock Germany) of 10 µl, conducted at a field strength of 20 mT, at an excitation frequency of 25 kHz, and the measuring time was 4 ms. The corresponding spectrum of 100 measured periods is presented in Figure 2 and corrected by background noise. The third harmonic of the 75 kHz marker was selected as an indicator for signal-to-noise ratio (SNR) of 49.77 dB, which clearly shows all odd harmonics up to the resonance peak, which is evident at around 825 kHz.Compared to other conventional spectrometer setups, the resonance frequency is quite low, but it is well suited for characterising particles for magnetic particle scanners, which typically have even lower resonant frequencies due to their large bore size. In addition, the attenuation of the cancellation unit was quantified using

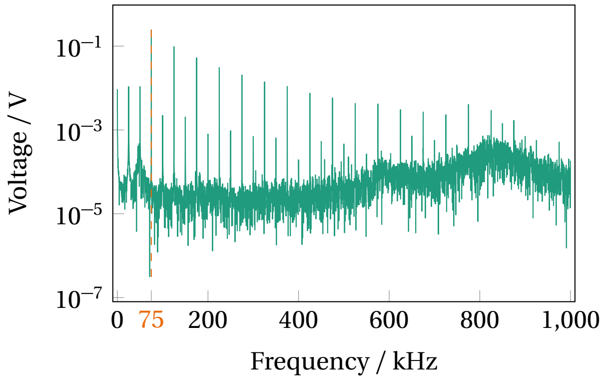

Figure 2: Measured spectrum of the sample containing background subtraction. All harmonics are clearly visible and the third harmonic (75 kHz) is marked as it is used for the SNR calculation.

a spectrum analyser and found to be −50 dB at the excitation frequency. This is comparable to the performance of state of the art spectrometers.

IV. Conclusion

A novel technique for manufacturing different coils for magnetic particle spectrometers using electronic additive manufacturing has been presented. This technique overcomes the disadvantages of fine-tuning, manufacturing discrepancies, and high labor costs while retaining the advantages of creating modular and flexible coil setups. Depending on the specific requirements of a researcher, the setup can be selected and in order to meet the desired needs of the application.

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Author's statement

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