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# Development and Assessment of a 1D-MPS

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**Abstract**

A novel one-dimensional modular magnetic particle spectrometer (1D-MPS) is herein presented, constructed to address the inherent limitations and stability issues associated with its predecessors. The design permits modifications at the component level, ensuring a flexible as well as adaptable system and features a robust decoupling of receiver and transmitter paths, effective shielding of signal components, and improved mechanical decoupling. The preliminary evaluation of the system shows promising results with regard to stability and reproducibility, indicating its potential to enhance measurement results across a range of applications.

## I. Introduction

Magnetic particle spectroscopy (MPS) is a technique that enables the characterisation of magnetic nanoparticles (MNP) through the measurement of their non-linear magnetisation response to an external time-varying magnetic field. This method has a diverse range of applications in both scientific research and industry. The essential examination of particle characteristics entails the assessment of magnetisation, size distribution, and their suitability for utilisation in magnetic particle imaging (MPI) systems [1]. A variety of additional applications has been documented which measure influence factors that extend beyond the intrinsic properties of particles, such as measuring MPI system matrices and using MNP as universal sensors in a wide range of bio- and immunoassays, wherein stability and detection limit are key parameters [2]. Despite promising preliminary results, the stability issues inherent to previous in-house designs have negatively impacted their long-term reliability. This paper presents the design of a modular 1D-MPS for long term stable, highly sensitive and comparable measurements.

## II. Methods and materials

Main drawbacks of current MPS systems is their influence on systematic errors within the measurement procedure, like sample positioning, temperature drifts, transfer function drifts and more. For diagnostic research purposes these errors introduce a strong deviation between measurements making small variations undetectable. Within the work presented here, the design decisions were taken in order to reduce systematic errors. This resulted in a modular system architecture that permits modifications at the component level through predefined interfaces, thereby facilitating adaptation to specific test or measurement requirements. These requirements include a robust geometrical decoupling of the receiver path from the transmitter path to improve the quantifiability of the measurements [1]. Additional prerequisites include the implementation of shielding mechanisms for signal-carrying components to mitigate external interference, the enhancement of the receive coils' homogeneity, the reduction of mechanical interference by mechanical decoupling of sample and measurement device, as well as the capacity to accommodate a variety of sample receptacles. Basic specifications were defined to include a maximum drive field amplitude of 30 mT at 25 kHz. The construction of both the electrical and mechanical elements is structured as a symmetrical, parallel system incorporating two identical transmit- and receive units. One unit is dedicated to the actual measurement, while the other serves as cancellation unit for decoupling. The geometric decoupling of the transmit and receive chains is achieved through the utilisation of the cancellation unit as a gradiometric-like circuit of the receive coils. This results in the superposition of 180° phase-shifted induced excitation voltages, thereby achieving a attenuation of $< -65$ dB in this work. A major feature of the mechanical implementation is an adjustment mechanism for the two coaxially mounted coils in each unit. Optimal decoupling requires ideally phase-shifted signals of equal amplitude in both receive coils, a requirement that is challenging due to variations in impedance, parasitic capacitive couplings, phase-shifts by feed-lines and production and position tolerances. Therefore, an adaptive design has been implemented that enables the coil position to be adjusted to compensate for differences in the induced receive signals by changing the relative position of the transmit field in the cancellation unit. Furthermore, a specifically designed sample holder was constructed to guarantee free suspension of the probe, thereby preventing any force on the coil during the insertion or extraction processes. This design ensures that the decoupling is not compromised, while additionally providing the option to adjust the position of the sample independently. In order to guarantee the same excitation field generation, and therefore a high decoupling, the geometrically identical send coils are connected in parallel and protected by identical copper shielding. In order to facilitate the measurement of low concentration samples in larger volumes while maintaining a high signal-to-noise ratio, the initially implemented modular receive coil is a coil with 14 mm free bore and a substantial homogeneous sensitivity range with ±2.3% deviation inside the largest possible sample vial ($\varnothing_{\text{in}} = 10$ mm) filled with 1 ml. The recieve chain provides in a measurement bandwidth of approximately 2 MHz, defined by the resonance between the receive coil and the low noise amplifier. A series of preliminary experiments at 20 mT was performed to ascertain the long-term stability and reproducibility of the measurements. This series comprises of 100 empty measurements taken at intervals of 5 s, with each measurement comprising 10 frames of 10 periods averaged 100 times. The evaluation is based on the amplitude spectra of the respective 10 contiguous periods per frame, with consideration given to both the total harmonic distortion (THD) and the amplitude of the feedthrough of the excitation field frequency.

# III. Results and discussion

The implementation resulted in a functional 1D-MPS capable of generating a phase and magnitude controlled peak excitation field of up to 30 mT. The results of the preliminary study indicate minimal discrepancies across the 1000 measurement points. The findings confirm a stable and interference-free excitation field, as only a small ratio (0.18 %) of the signal components correspond to higher harmonics. This is demonstrated by the low value and deviation of the THD in both the reception path ($\mu = 0.001\,83, \sigma = 0.000\,43$) and the feedback signal ($\mu = 0.000\,38, \sigma = 0.000\,01$). The minimal standard deviation of the feedthrough amplitude observed for both the receive path ($\mu = 561\,\text{mV}, \sigma = 2.95\,\text{mV}$) and the feedback channel ($\mu = 20\,\text{mT}, \sigma = 4\,\mu\text{T}$) suggests a high level of overall system stability. Despite the constant excitation field strength, which is guaranteed by the field control throughout the entire measurement series, a marginal drift of approximately 2 % of the feedthrough amplitude can be observed. This indicates a discrepancy between the excitation and cancellation fields over time, which can be regarded as inconsequential, when considering the timespan of typical consecutive background-corrected measurements.

# IV. Conclusion

The development, implementation and preliminary assessment of the modular 1D-MPS have yielded encouraging results and the modular design of the system will ensure the adaptability towards future demands.

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# Author's statement

Authors state no conflict of interest.

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