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Single-Chain Architecture in a Multi-Channel Magnetic Particle Spectrometer

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Abstract

Magnetic particle spectrometry (MPS) is a valuable tool for characterizing the magnetic properties of magnetic nanoparticles (MNPs), which significantly affect image resolution in MPI. As a result, extensive research is dedicated to enhancing the magnetic properties of MNPs. This research focuses on the design and development of a multi-channel MPS system with five channels, each operating at 20 mT, to track nucleation and growth processes and to ensure quality control in flow-based synthesis.

I. Introduction

A multi-channel Magnetic Particle Spectrometer (MPS) represents an advanced approach to the simultaneous characterization of MNPs, enhancing the capabilities of traditional MPS systems. This advancement transforms the traditional MPS device from a post-characterization tool into a real-time monitoring system to track MNPs across diverse applications. This innovative instrumentation enables for the parallel analysis of multiple nanoparticle samples, significantly increasing throughput and efficiency in magnetic property assessment. Furthermore, it can be used for the analysis of nucleation and growth of MNPs in a continuous flow setup for large-scale production of MNPs providing quality check for various applications [1].

In this research, the focus is on the design and development of a Multi-Channel MPS system having five different MPS channels for simultaneous measurements of MNPs.

II. Methods and materials

Figure 1 shows the different modules of the Multi-Channel MPS system, which are (1) the personal computer with the acquisition card (Red Pitaya) producing the excitation signal of 25 kHz and also receiving the MNPs' response. The power amplifier (AE Techron 2105) (2) amplifies the excitation signal from the acquisition card. It sends it to (3) the impedance matching unit, which matches the reactance of the transmit coil to the desired impedance of the power amplifier. (4) The signal is then fed to the transmit coil in the field generator unit, which produces a magnetic field of 20 mT to excite the

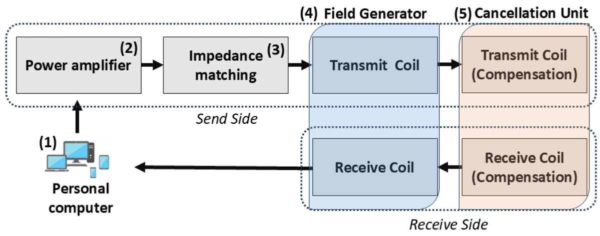

Figure 1: Block diagram of single channel consisting of the different modules of Multi-Channel MPS system

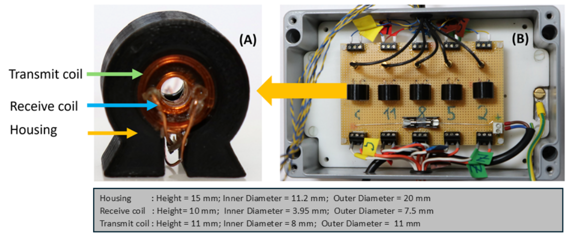

Figure 2: (A) shows a single field generator with dimensions mentioned below and (B) shows the cancellation unit consisting of five pairs of field generators

MNPs. The receiving coil acquires the MNP response and sends it back to the personal computer to be analyzed. To monitor the amplitude of the field produced by the transmit coil, a sensing coil is concentrically placed outside the housing of the field generator, and this voltage signal is also fed back to the acquisition card. In the end, a personal computer is used to display, store, and analyze data. In addition, a cancellation unit (5) for the mirrored field generator is used to eliminate the feed-through excitation frequency, which has a significantly larger amplitude than the signals received from the MNPs. All send coils are connected in series to the power amplifier and have a single impedance matching unit, and all received signals are acquired simultaneously using multiple acquisition boards. In this research, the focus will be on a single channel. To determine the sensitivity of a single channel a commercially available mixture of MNPs called Resovist was used. Resovist is a multicore particle with an iron oxide core, consisting of many single crystals.

III. Prototyping and Results

III.I. Field generator

The field generator consists of the transmission coil and the receiving coil in a 3D printed housing. The inner diameter of the transmitting coils is 8 mm and the outer diameter of 11 mm with a height of 11 mm. The inductance of the transmit coils is approximately 24 µH and the resistance is 375 mΩ. On the other hand, the outer diameter of the receive coils is 7.5 mm and an inner diameter of 3.95 mm which could easily fit a 10 µl in terms of total sample volume. The inductance of the receive coils is approximately 3.4 µH and the resistance is 135 mΩ. Figure 2(A) shows the field generator with its housing.

III.II. Cancellation unit

The amplitude of the transmitted signal is several orders of magnitude higher than the signals received from the MNPs. To attenuate the transmitted signal, an identical pair of coils—one transmit and one receive—is inverted and connected to the field generator. Figure 2 (B) illustrates the cancelation unit, which houses five identical but inverted field generators. The total attenuation provided by the cancellation unit is approximately -44.3 dB.

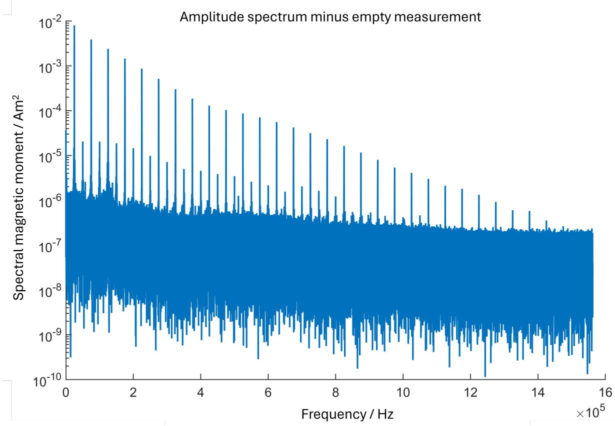

Figure 3: MPS measurement showing the sensitivity of the device with a 10 µL Resovist sample

Figure 3 shows the amplitude spectrum of the 10 µL sample. The odd harmonics could be easily detected till 1.4 MHz showing enough sensitivity to detect MNPs.

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Author's statement

Conflict of interest: Authors state no conflict of interest.

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