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DC Bias for Improved Baseline Acquisition on a Magnetic Particle Spectrometer Setup

Gulin Canturk [a*,†] · Ege Kor [a,b,†] · Emine Ulku Saritas [a,b]

[a] Department of Electrical and Electronics Engineering, Bilkent University, Ankara, Turkiye
[b] National Magnetic Resonance Research Center (UMRAM), Bilkent University, Ankara, Turkiye
[†] Shared first authorship
[*] Corresponding author, email: gulin.canturk@ug.bilkent.edu.tr

Abstract

Magnetic particle spectrometer (MPS) setups typically feature a manually adjusted receive coil to minimize direct feedthrough interference. These adjustments can be compromised when a sample is physically inserted into the MPS setup or when a lengthy experiment is performed. In this work, we propose an MPS setup with a DC bias coil that can completely saturate the magnetic nanoparticle (MNP) signal, enabling baseline signal acquisition when the MNPs are inside the receive chamber.

I. Introduction

In a standard magnetic particle spectrometer (MPS) setup, the drive and receive coils are decoupled to avoid direct feedthrough interference. In setups with a gradiometric receive coil, typically the position of one section of the receive coil is manually adjusted before acquiring a baseline signal. If the decoupling of the drive and receive coils is sensitive to this adjustment, the calibration of the setup may be compromised when physically placing the magnetic nanoparticle (MNP) sample into the receive chamber or during lengthy experiments.

Previously, MPS setups with DC bias coils have been utilized to characterize the magnetization response of MNPs for a wider range of applied fields [1]. In this study, we propose an MPS setup equipped with a DC bias coil to completely saturate the MNP signal, such that the baseline signal can be acquired while the MNP sample is inside the receive chamber. This setup enables back-to-back measurement of the baseline signal and the MNP signal without any physical contact with the setup, as well as acquisition of intermediate baseline signals during experiments without removing the sample.

II. Materials and Methods

II.I. Saturation with DC Bias Field

As the applied magnetic field increases beyond a certain threshold, the MNP magnetization saturates, causing the MNP signal to diminish [2]. Using this well-known principle, we propose applying a strong DC bias field in addition to the drive field (DF) during baseline signal acquisition. This DC field is then turned off for MNP signal acquisition.

To determine the strength of the DC bias field needed to sufficiently saturate the MNP magnetization, simulations were performed (1) based on ideal Langevin response of MNPs and (2) based on the Fokker-Planck equation for coupled Brown-Néel rotation [3]. The simulation parameters were: 20 nm core diameter, 60 nm hydrodynamic diameter, anisotropy constant of 6000 J/m^3, 10 kHz and 10 mT DF settings, with a collinear DC field ranging between 0-60 mT.

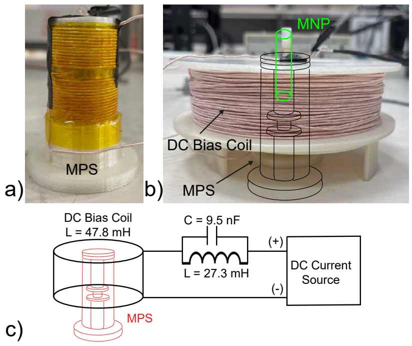

Figure 1: a) In-house arbitrary waveform MPS setup and b) the DC bias coil placed coaxially with the MPS setup. c) The peripheral circuitry of the DC bias coil.

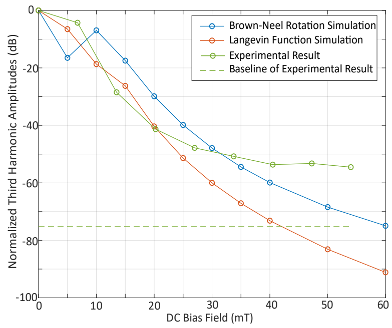

Figure 2: Simulation and experimental results for third harmonic amplitude as a function of DC bias field.

II.II. Experiments

The experiments were conducted on our in-house arbitrary waveform MPS setup shown in Fig. 1, at 10 kHz and 10 mT DF settings. The DC bias coil (see Fig. 1b) had 13.5 mT/A sensitivity over the receive chamber. The drive field can induce voltages and currents on the DC bias coil, which can in turn cause a secondary induction on the receive coil. First, to minimize eddy current formation, the DC bias coil was wound using a Litz wire. In addition, a parallel LC tuned circuit resonant at the DF frequency was connected in series with the DC bias coil (see Fig. 1c), to prevent secondary induction due to currents induced through the DC bias coil at DF frequencies [4].

First, to evaluate the signal saturation performance, the DC bias field was varied between 0 and 54 mT. These experiments were performed on a 100 µL sample of undiluted 8.5 mg Fe/mL Perimag (Micromod GmbH). Next, the performance of the MPS setup with the DC bias coil was compared with the standard MPS setup using a dilution series of Perimag. Starting with undiluted Perimag and performing 2X dilution in each step, samples at 12 different concentrations were prepared. Importantly, with the DC bias coil, the baseline and MNP signals were acquired back to back with the sample inside the receive chamber, but with DC bias field turned on and off, respectively.

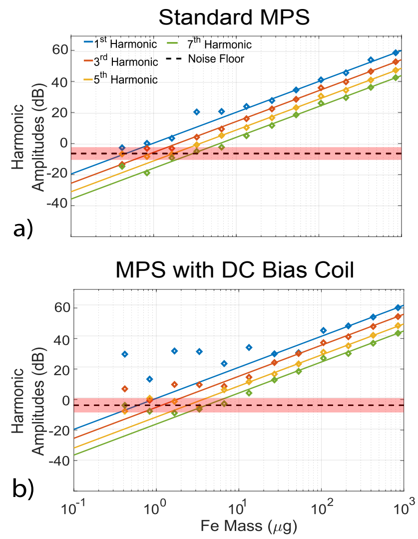

Figure 3: Harmonic amplitudes with respect to iron mass for (a) standard MPS setup and (b) MPS with DC bias coil.

III. Results and Discussion

Simulation and experimental results in Fig. 2 demonstrate that a considerable level of signal saturation can be achieved if a sufficiently high DC bias field is applied. In the experiments, 52 dB reduction in the third harmonic of the MNP signal was achieved with a 40 mT DC bias field. Increasing the DC bias field beyond 40 mT did not provide significant benefits.

Figure 3 shows the results of the dilution series experiments for the standard MPS setup and the MPS setup with DC bias coil. The MPS setup with DC bias coil has a slightly higher noise floor (approximately 1.4 dB higher). Importantly, the sensitivities of the two setups are comparable for higher harmonic signals. With that said, the MPS setup with DC bias coil shows an increased signal floor for the 1st harmonic, potentially stemming from interference due to residual secondary induction caused by the DC bias coil.

While the signal saturation performance shown in Fig. 2 depends on the MNP type and the magnetization curve of the MNP, it does not depend on the MNP concentration level. Regardless of concentration, reducing the MNP signal by 52 dB (approximately 400 fold) during baseline acquisition makes its contribution to the baseline signal negligibly small when compared to the MNP signal acquired without DC bias field.

IV. Conclusion

This work proposed an MPS setup with a DC bias coil to saturate the MNPs, so that baseline acquisition can be performed with the MNPs inside the receive chamber. This setup facilitates back-to-back measurement of baseline and MNP signals and intermediate baseline acquisitions during long experiments.

Acknowledgments

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Author's statement

Authors state no conflict of interest.

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