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Insight COMPASS – the physics behind

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Abstract

Critical Offset Magnetic PArticle SpectroScopy (COMPASS) is a new method that allows to detect slight changes in the mobility of particles in a solution very sensitively. While first applications in detecting biomarkers such as SARS CoV 2 antibodies show very promising results, the full potential of the technique and the underlying physical effects were yet only considered superficially. Here we present the first results of a detailed study of the behavior of the particle signal under variations of relevant system parameters with a focus on particle size, viscosity and temperature of the solution to win more information about the behavior of the effect and find new interesting application possibilities.

I. Introduction

Magnetic Nanoparticles (MNP) become more and more relevant in many research fields due to their high potential for medical but also technical applications [1]. The option to functionalize the coated surface of the particles extends their potential especially in life sciences, since this makes it possible to detect specifically targeted biomolecules or biomarkers [1].

Already several techniques like AC susceptometry (ACS) [2] or magnetic particle spectroscopy (MPS) [3] have taken advantage of the properties of functionalized MNPs to use them for detection of biological substances. The new and very promising method Critical Offset Magnetic Particle Spectroscopy (COMPASS) shows a significant improvement in sensitivity compared to the ones mentioned above [4]. With small technical effort and within seconds COMPASS allows to detect minimal changes in the mobility of the MNPs and thus to prove the successful binding of specifically addressed biomarkers. As an example, COMPASS is able to detect SARS CoV 2 antibodies with an accuracy similar to established methods like ELISA [5] or flow cytometry [6].

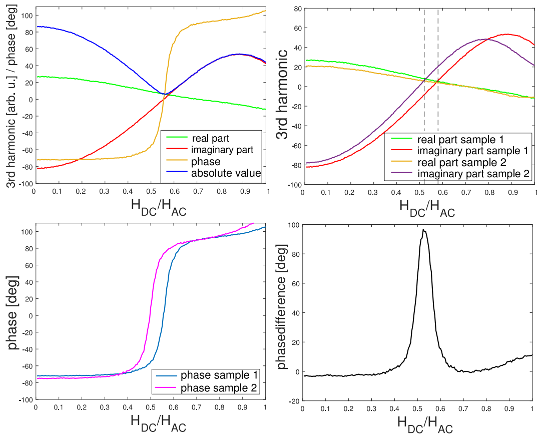

Figure 1: Simulation of real and imaginary part, phase and absolute value of the third harmonic of a particle signal with an additional varying offset field, showing a prominent CP (Top left). The intersect of real and imaginary part of the signal of two different particle samples with different particle mobility show a slight shift (Top right), as well as the phase of the two signals (Bottom left). The phase difference of the two different particle samples shows a clear peak due to the slight shift of the critical point.

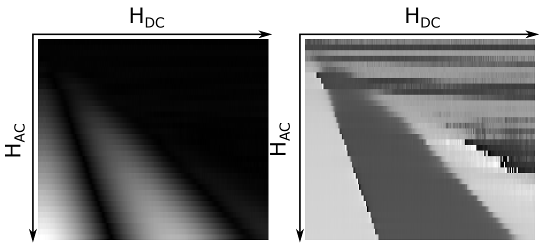

Figure 2: Two-dimensional visualization of amplitude (left) and phase (right) of the fifth harmonic by varying the AC- and the DC-field.

In this context it is of interest to examine the physical origin of the underlying effect more precisely. Here, we aim to present the results of a fundamental analysis of parameters of the particle ensemble and their influence on the COMPASS measurement method.

II. Materials and Method

The concept of a COMPASS measurement is based on a modification of MPS. The main difference is the addition of a constant offset field H_{DC} to the existing oscillating excitation field H_{AC}.

$$H_{ext} = H_{AC} + H_{DC} \, . \tag{1}$$

This add-on leads to the formation of so-called critical points (CP), that are characterized by the suppression of the spectral signal of a certain higher harmonic.

Tracking the amplitude of one specific harmonic for various offset field strengths H_{DC}, one yields a characteristic curve, which resembles the Chebyshev polynomials of second kind [7]. This curve shows minima that are also referred as nodes close to the intersect of real and imaginary part of the signal. These nodes are the CPs, which appear at characteristic ratios of excitation H_{AC} and offset field H_{DC} that are specific for each higher harmonic. When analyzing the complex signal values of this curve, a very steep change in phase is visible in the vicinity of the CPs.

Due to this jump-like behavior of the phase, the CPs are highly sensitive to small changes in the particle mobility, which lead to a slight shift of the CP's position along the H_{DC} axis.

The goal is to investigate, which influences on the particle system induce a variation of the position of a CP. This is done by assuming the particle ensemble to follow the Langevin-equation

$$\frac{d\mathbf{m}}{dt} = \frac{1}{6\eta(T)V}\left(\mathbf{m}\times\mathbf{B} + \sqrt{2D(T)}\mathbf{N}\right)\times\mathbf{m}, \tag{2}$$

which describes the behavior of a single particle magnetic moment m in an external magnetic field B, considering a statistical part containing the noise force N and the Einstein-Smoluchowski-diffusion-constant *D(T)*. It further depends on the viscosity η and indirectly the temperature T of the particle solution, as well as the hydrodynamic volume V of the particles [8]. These parameters affect the mobility of the particles and are therefore of big interest for finding the origin of the induction of the slight shift in the CP position.

III. Results and discussion

For a first classification of the occurrence of CPs, four-dimensional data sets were generated for a comprehensive analysis of the CP positions. Two of the four dimensions cover the variation of excitation H_{AC} and offset field H_{DC} for one certain harmonic, while the third dimension represents the range of even and uneven harmonics of the measured signal.

The fourth dimension is used for different parameters whose variation may lead to a shift of the CP position. In this context, the focus lies on the parameters size, viscosity and temperature of the particles or the particle solution, respectively. Figure 2 gives an impression of the data handling of these datasets by visualizing two of the four dimensions, in this case, the AC- and DC-field. The two-dimensional phase and amplitude plots show a CP for nearly constant ratios of the AC- and the DC-field. The influence of the parameters affecting the particle mobility can be measured by the modification of this characteristic and unique ratio.

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IV. Conclusions

COMPASS is a promising method for a highly sensitive analysis of magnetic nanoparticle ensembles and their modification. Within the scope of extensive analyses, different influences on the particle system like size of the particles, viscosity or temperature of the particle solution were investigated to find out how sensitive the COMPASS measuring method reacts to their modifications. On the one hand, these analyses aim to contribute to a better understanding of the physical effect underlying the measurement, but on the other hand, the potential of the method is tested with respect to further fields of application, also outside biomedical analytics.

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Author's statement

Conflict of interest: Authors state no conflict of interest. Informed consent: Informed consent has been obtained from all individuals included in this study.

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