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Magnetic particle fingerprinting using COMPASS

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Abstract

To bring the application of magnetic nanoparticles (MNP) closer to application, reliable properties of a MNP suspension need to be ensured for reproducible quality and stability. This aims for a simple, robust and sensitive method that is able to assess the unique characteristics of MNP. We suggest Critical Offset Magnetic Particle SpectroScopy (COMPASS) as a suitable method for these needs, hence it allows for measuring a fingerprint characteristic for a unique MNP suspension. In the following, a dedicated fingerprinting routine to distinguish and classify different magnetic particle types will be introduced.

I. Introduction

The importance of magnetic nanoparticles (MNP) in medical, biological and technical applications has been constantly growing in the recent years [1]. Especially for their use in medicine, quality control and classification of various MNP types in commercial and academic development is of high interest [2]. Thus, a robust yet sensitive method is needed to enable monitoring of specific particle properties of each produced batch [3].

Here, we suggest Critical Offset Magnetic PArticle SpectroScopy (COMPASS), which is a new method to detect very small differences in the mobility of MNP, as a suitable technique for MNP quality control [3]. The method is highly interesting for many applications regarding MNPs, for example in- vitro diagnostics based on functionalized MNPs [3]. We present a measurement and data processing routine to enable the creation of unique fingerprints of magnetic nanoparticle suspensions. These fingerprints may encode information about different particle properties that can influence their usability.

II. Materials and methods

COMPASS is an extension of the concept of Magnetic Particle Spectroscopy (MPS). While MPS is based on measuring the MNP answer to an oscillating magnetic field, COMPASS complements this method by adding an additional offset field. When the acquired signal is Fourier transformed, the corresponding spectrum differs from the conventional MPS spectrum. At characteristic com-

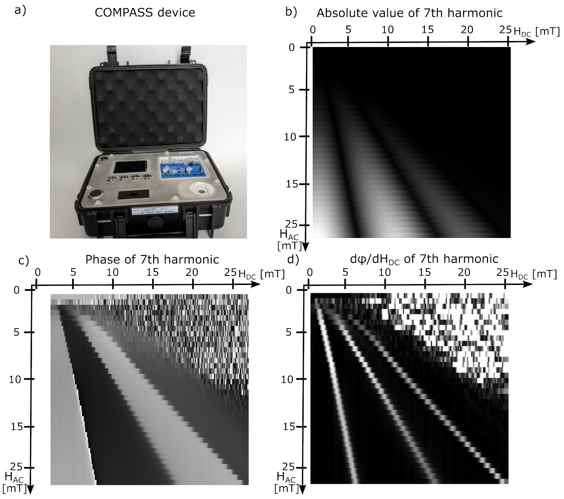

Figure 1: (a) portable COMPASS device. (b) absolute value, (c) phase and (d) derivative of the phase in H_{DC} direction of the 7^{th} harmonic of the signal spectrum of Synomag® (Micromod GmbH, Germany). Spectra were measured for a range of H_{DC} and H_{AC} field strengths from 0 mT to around 25 mT.

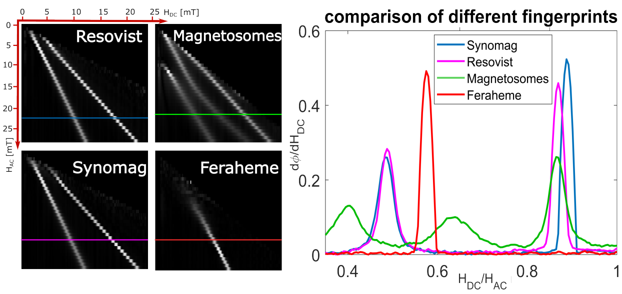

Figure 2: left: CP fingerprints of the 6^{th} harmonic of different MNP types (Resovist®, Synomag®, Feraheme® and Magnetosomes [5]). Right: comparison of the CP-peak shapes of the different MNP types at $H_{AC} = 18.85$ mT.

binations of offset (H_{DC}) field and oscillating (H_{AC}) field strength the amplitude of higher harmonics of the spectrum decreases significantly. In the vicinity of this strong decrease, the phase of the complex signal shows a steep phase change whose position is characteristic for the respective particle system and highly sensitive towards any changes of the system, that lead to a variation in the particle mobility. The higher the harmonic the higher the number of occurring phase changes, which are referred to as critical points (CP).

To acquire a complete COMPASS fingerprint of a particle ensemble, a range of different parameters can be varied, suggesting the arrangement of the data in a multidimensional dataset of the spectroscopic information. Thus, the Fourier transformed complex signal for varying H_{DC} (1^{st} dimension) and H_{AC} (2^{nd} dimension) from 0 mT up to around 25 mT is acquired for each higher harmonic (3^{rd} dimension). When comparing different particle types, the 3D fingerprint of each sample can be combined ending up with a 4D dataset.

For a more comparable visualization of the CPs, the derivative $\frac{d\varphi}{dH_{\text{DC}}}$ of the phase φ is calculated, which leads to a peak-like shape of the steep phase changes (see Fig. 1).

III. Results and discussion

Characteristic fingerprint patterns of different types of commercially available MNPs have been acquired using the COMPASS measurement method. When comparing the positions and characteristics of the pattern at the same H_{AC} field strength, differences in position and shape of the peaks marking the critical points occur. This indicates that each particle system exhibits a unique CP-pattern depending on their properties. There is a wide range of parameters that are suspected to cause a change in the CP pattern. Since the COMPASS method is sensitive towards the particle mobility, influences like particle size and shape or viscosity of the suspension may lead to CP shifts. Another considerable influence on the particle behavior is temperature, which did not have an impact on the measurements shown in Fig. 2, since the setup and sample were kept at constant temperature.

IV. Conclusion

COMPASS is a new highly sensitive measurement method, which provides information about the mobility of MNPs. This allows to acquire unique fingerprints for each MNP system. Thus, COMPASS is highly interesting for detecting differences between different particle systems or batches. Due to the uncomplicated hardware of the portable system, COMPASS may be a suitable candidate for online quality control during the particle synthesis.

Another important aspect of MNP quality is the control of long-term colloidal stability during particle storage, which can express for example as cluster formation. This change in size and shape of the particles can also induce changes in the COMPASS fingerprint.

Since COMPASS is a magnetic measurement method it has the additional potential to address the magnetic properties of the particles. Thus, COMPASS may has the capability to combine the measurement of structural and magnetic properties of MNPs.

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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