Characterizing and Imaging Magnetic Nanoparticles by Optical Magnetometry

A. Weis*[1], S. Colombo [1], V. Dolgovskiy [1], Z. D. Grujić [1], S. Pengue [1], V. Lebedev [1]
1. Department of Physics, University of Fribourg, Chemin du Musée 3, 1700 Fribourg, Switzerland

Biomedical applications of magnetic nanoparticles (MNP) witness a rapid development over the past decade. The targeted drug delivery by functionalized MNPs demands fast, sensitive and reliable techniques for characterizing the size distribution and other physical MNP sample parameters. In the past 4 years we have deployed atomic magnetometers (AM) for various MNP studies, viz., (•) the precision measurement of blocked MNP size distributions, their saturation magnetization, anisotropy constant, and iron content using AM-detected magneto-relaxation (MRX) [1], (•) the imaging of the magnetic field pattern from magnetized MNP by an AM-based "Magnetic Source Imaging Camera" (MSIC) [2], and more recently, source reconstruction from the field images as well as (•) the recording of $M(H)$ magnetization curves [3] and magnetic AC-suceptibilities $\chi_{AC} = dM(H)/dH$ [4] of liquid suspended MNPs by an AM. I will briefly review these studies and then focus on our recent (unpublished) demonstration of AM-based 1D and 2D MPI (Magnetic Particle Imaging) scanners based on atomic magnetometry, which closely follows the method proposed in Ref. [5].

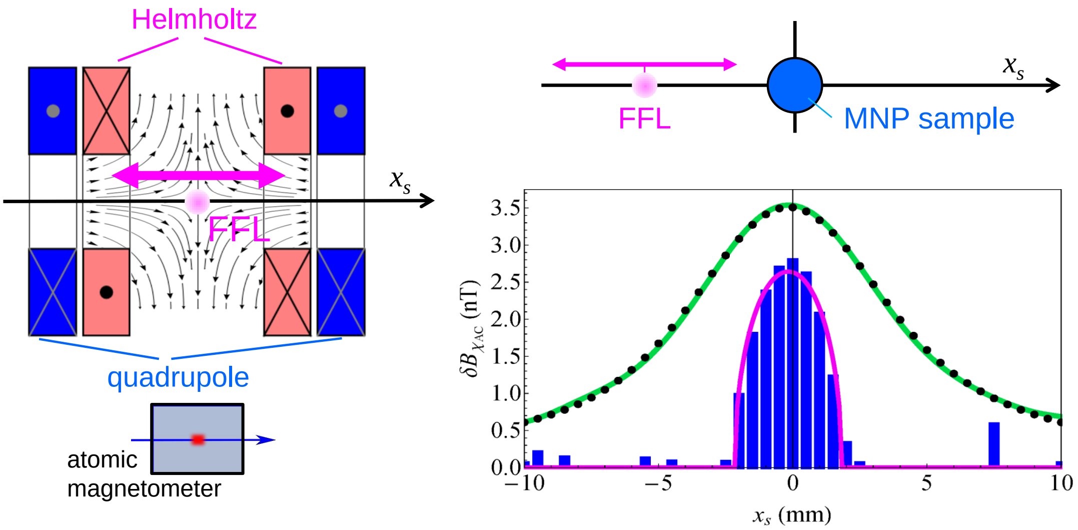

Fig. 1: Left: Principle of 1D-MPI scanner with gradient and homogenous field coils producing a field-free line (FFL), whose position can be moved along the x_s axis by scanning the the Helmholtz coil current (compensation coils [5] not shown). Right: Raw magnetometer signal (green line) from a cylindrical 4 mm diameter MNP sample, and inferred 1D MNP density distribution (blue histogram) and reconstructed signal (black dots).

Details of the MPI scanner are shown in Fig. 1. A cylindrical quadrupole field with a field-free line (FFL) is produced by 4 straight conductors. A homogeneous field produced by a second set of straight conductors is superposed on the quadrupole field, thus allowing to displace the FFL along the x_s direction. Right, top: An MNP sample (4 mm inner diameter capillary filled with ∼50 μl of Ferrotec© EMG707 ferrofluid, oriented parallel to the FFL) is located at the center of the coil system. A nearby atomic magnetometer measures the field produced by the magnetized MNPs. A field modulation technique with lock-in demodulation is used to detect a signal only when the FFL is in the vicinity of the MNP sample. Raw magnetometer data are shown as green line on the lower right. Deconvolution of the raw data with the known system point-spread function allows us to infer the MNP density distribution (blue histogram), which reproduces well the known density distribution (magenta line). The black dots represent the reconstruction of the experimental signal from the inferred density distribution.

I refer to the poster by V. Lebedev et al. for details of the method and its extension to two dimensions.

References

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*Corresponding author: antoine.weis@unifr.ch