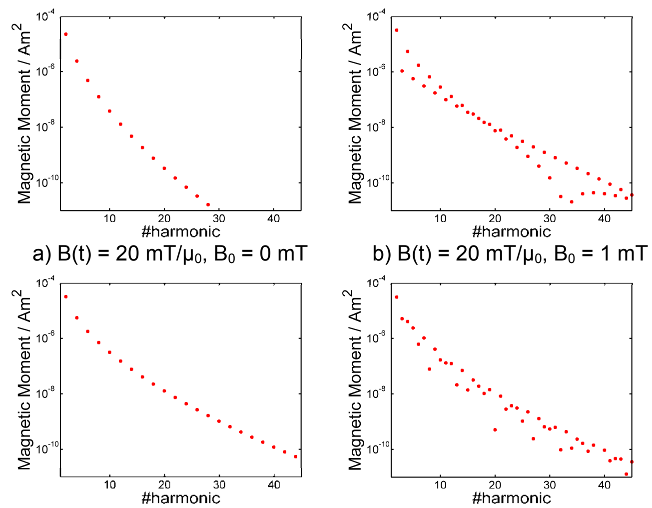
Improved Estimation of the Magnetic Nanoparticle Diameter with a Magnetic Particle Spectrometer and Combined Fields

S. Biederer[1], T. Knopp[1], T. F. Sattel[1], M. Erbe[1], and T. M. Buzug[1]
[1]Institute of Medical Engineering, University of Luebeck, Luebeck, Germany

Introduction: In the tomographic imaging technique magnetic particle imaging (MPI), the spatial distribution of super-paramagnetic iron-oxide nanoparticles (SPIOs) can be visualized in real-time [1, 2, 3, 4]. MPI takes advantage of the nonlinear magnetization behavior of the SPIOs. In simulations it has been shown [5, 6] that the iron-core diameter has a high impact on the received signal and, thus, also on the imaging quality. For prediction of the imaging quality or for a model-based reconstruction [7], the knowledge of the exact iron-core size distribution is indispensable. However, an estimation of the iron-core size e.g. by transmission electron microscopy is complicated and time consuming. A magnetic particle spectrometer (MPS) exploits the same physical effect as used in MPI. Based on MPS measurements, a new method to estimate the iron-core size distribution was proposed [8]. In this contribution an improvement of this estimation method is presented by using combined excitation fields.

Methods: When a time-varying pure sinusoidal magnetic field is applied to SPIOs, the magnetization response does not only contain the fundamental frequency f_0, it also contains higher harmonics (i.e. multiples of f_0). In [9] a single magnetization spectrum is measured at a certain field strength. This spectrum is used to determine the expectation value and the standard deviation of the iron-core size distribution by solving a minimization problem. Due to symmetry of the sine-wave excitation, the magnetization spectrum only contains odd harmonics. To improve the condition of the minimization problem, it is possible to measure multiple spectra at different field strengths. A different way is to keep the amplitude of the alternating field unchanged and superimpose it with an offset field. Now, the excitation is asymmetric and, thus, the spectrum also contains even harmonics.

Results: In Figure 1 simulated magnetization spectra at different field strengths without offset as well as spectra at a certain field strength with different offsets are shown. It can be seen that in the presence of an offset field the even harmonics are intensified. Also, the spectra with offset differ more among one another compared to spectra without offset. This results in a better conditioned minimization problem. Figure 2 illustrates the error of the minimization problem for the procedure proposed in [9] at a field strength of 20 mT/μ0 (a), for using 9 different filed strengths between 5 and 20 mT/μ0 (b), and for a single field strength of 20 mT/μ0 with 9 different offsets fields between 0 and 10 mT/μ0 (c). Using different field strengths does not significantly change the error. However, the minimization problem has a much sharper minimum when using different offset fields. Hence, a much better condition is reached resulting in a more stable estimation of the iron-core size distribution.

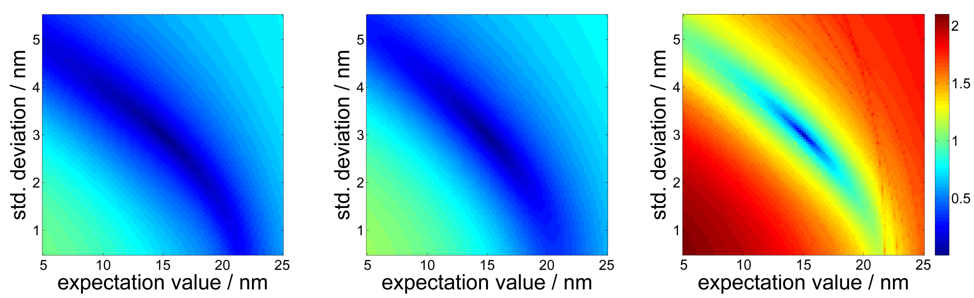


a) B(t) = 20 mT/μ_0, B_0 = 0 mT   b) B(t) = 20 mT/μ_0, B_0 = 1 mT

c) B(t) = 10 mT/μ_0, B_0 = 0 mT   d) B(t) = 20 mT/μ_0, B_0 = 5 mT

Fig. 1: Magnetization spectra at different field strength B(t) without offset field B_0 and at a certain field strength with different offset fields.

Discussion/Conclusion:
It has been shown, that using offset fields improves the condition of the minimization problem. Thus, a more stable estimation of the iron-core size distribution is feasible. This is important for predicting the imaging quality or for a model-based reconstruction. Further work is required to determine the optimal number of offset fields as well as the optimum range of the offset field strengths.



a) Single Field   b) Multiple field strengths   c) Multiple offset fields

Fig. 2: Error plots for different combined fields.

References:

[1] B. Gleich, 2005, Nature, 435:1214-1217.
[2] B. Gleich, 2008, PMB, 53:N81-N84.
[3] J. Weizenecker, 2009, PMB, 54:L1-L10.
[4] T.F. Sattel, 2009, JPhysD, 42(2):1-5.
[5] J. Weizenecker, 2007, PMB, 52:6363-6374.
[6] S. Biederer, 2009, MAGMA, 22(S1):499.
[7] T. Knopp, 2009, TMI, 28(12).
[8] S. Biederer, 2009, JPhysD, 42(20):7pp.