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Reconstruction of magnetic nanoparticle distributions in organs by magnetic multipole expansion

Wiekhorst F.[1], Baumgarten D.[2], Haberkorn W.[1], Steinhoff U.[1], Haueisen J.[2], Baer M.[1], Trahms L.[1]

[1] Physikalisch-Technische Bundesanstalt, Berlin, Germany
[2] Technische Universitaet Ilmenau, Ilmenau, Germany
frank.wiekhorst@ptb.de

Introduction

The accurate quantitative determination of magnetic nanoparticle distributions in biological tissue is an essential feature in the development of novel nanoparticle based medical applications like drug targeting and hyperthermia. Measurement techniques like magnetorelaxometry, susceptometry or remanence so far allow a sensitive as well as robust quantification and localization of focussed (point-like) nanoparticle accumulations in tissue or a reconstruction of nanoparticle distributions from individual measurements of a dissected organ. An ill-posed inverse problem has to be solved to reconstruct the underlying nanoparticle distribution from a magnetic field pattern.

Methods

We present a multipole based approach for the reconstruction of spatially extended nanoparticle distributions. The measured magnetic field distribution obtained by a multichannel SQUID system is parameterized by a spherical harmonic multipole expansion. We derived equations to quantify the total amount and localize the centre of the nanoparticle distribution from the multipole coefficients. Additionally, the spatial extent of the source distribution is estimated by means of a second multipole expansion using the afore determined centre of the nanoparticle distribution as expansion point.

Results

The net magnetic moment and the centre of a nanoparticle distribution are obtained from dipole and quadrupole components of the multipole expansion. The determination of source extent requires the inclusion of higher order multipolar terms. Using the PTB 304-SQUID system, the total magnetic moment of extended magnetic sources with dimensions up to 20 cm can be estimated with an uncertainty of less than 5%. Additionally, a mismatch of the localization below one centimetre is found for homogeneously magnetized source distributions.

Conclusion

Magnetic source reconstructions obtained from simulated and measurement data demonstrate feasibility and performance of our multipole based approach. Multipole expansion allows a fast as well as robust quantification and localization of extended nanoparticle distributions and additionally the estimation of principal source dimensions.