Towards Magnetic Induction Tomography Of Low Conductivity: A COMSOL Multiphysics Simulation

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Abstract

Background: Magnetic Induction Tomography (MIT) is an electromagnetic imaging technique that maps a material's electrical conductivity by inducing eddy currents via a primary oscillating magnetic field. The resulting secondary magnetic fields from the eddy currents are measured for image reconstruction and object characterisation. Performing MIT on low-conductivity samples (e.g. human tissue, saline) is valuable but challenging due to weak secondary fields. Optically pumped magnetometers (OPMs), known for high sensitivity, show promise for such applications. We present comprehensive COMSOL Multiphysics electromagnetic field modelling, image reconstruction algorithm development, and quantitative analysis of secondary field distributions.
Methods: COMSOL Multiphysics was employed to model the electromagnetic induction physics and calculate secondary magnetic field distributions for various conductivity scenarios. The AC/DC module was used to solve for the secondary field profiles, simulating eddy current generation. Test geometries included a 1-cm copper cube (conductivity = 5.998×107 S/m), copper 'letters', and a 1-cm cube with conductivities ranging from 1S/m to copper. Secondary field data extracted from COMSOL simulations were subsequently processed using a Minimum Norm Estimation (MNE) algorithm for image reconstruction. A magnetic dipole forward model estimated the dipole source distribution matching the secondary field patterns.
Results: COMSOL simulations were performed with samples positioned on a 10-cm square grid, with secondary fields calculated on a 1-cm resolution measurement grid located 1 cm from the sample surface. The forward model utilized 1-mm pixel resolution for high-fidelity reconstruction. MNE-derived images showed strong correlation with the ground truth geometries (coefficient ≈ 0.8). COMSOL parametric studies confirmed the expected linear relationship between material conductivity and secondary field magnitude. Simulation results indicate that a 150 µT primary field would induce a 300 fT secondary field at 6 mm from a 10 S/m sample.
Outlook: COMSOL-based simulation results demonstrate the feasibility of MIT for low conductivity samples using OPMs. The validated electromagnetic modelling framework will guide experimental validation of the generic reconstruction procedure using copper samples and fluxgate magnetometers. COMSOL insights will directly inform the optimal design parameters, coil configurations, and measurement strategies for the development and realization of an OPM-MIT system.

Reference

Kasper Jensen et al. “Detection of low-conductivity objects using eddy current measurements with an optical magnetometer”. In: Phys. Rev. Res. 1 (3 Nov. 2019), p. 033087

Figures used in the abstract

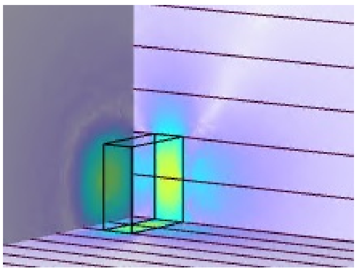

Figure 1 : Thumbnail: Magnetic field norm of secondary field due to a conductive object.