Magnetoquasistatic Simulation with Uncertainties and Applications in Magnet Design

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Input parameters for the numerical simulation of fields, such as material parameters, the geometry or source currents are not known exactly in practice, e.g., due to manufacturing imperfections. Therefore, modeling and quantifying uncertainties are important tasks to achieve a more robust design of devices. In this work, we address these issues in the context of magnetic field simulations, governed by the nonlinear magnetoquasistatic system.

Simulations with uncertainties can quickly become demanding due to the curse of dimensionality. To keep the computational effort reasonable we aim at both identifying a small number of important input parameters and efficiently propagating uncertainties to a physical quantity of interest of the system. A quantity of interest can be the field itself or derived global quantities, such as the energy, inductances or forces. Input uncertainties can be modeled as random fields, which are discretized, e.g., by the truncated Karhunen-Loève expansion yielding a finite number of random variables. The importance of each input variable is quantified by sensitivity measures, such as the Sobol coefficients. Statistical moments of quantities of interest in turn are computed by polynomial expansions in random-space, referred to as polynomial chaos, and adjoint perturbation techniques. An important aspect here is to examine to which extent linearization is permissible.

As a main application we address the field homogeneity of accelerator magnets. It is expressed by magnetic field Fourier harmonics, referred to as multipole coefficients. Multipoles have been found to be very sensitive to manufacturing imperfections. In particular, we investigate the sensitivity with respect to deviations in the BH-curve and the geometry of the magnet’s pole shape. Numerical examples for dipole and quadrupole magnets will be given.