Various two dimensional multi-scale finite element formulations for the eddy current problem in iron laminates

K. Hollaus and J. Schöberl
Institute for Analysis and Scientific Computing,
Technische Universität Wien, A-1040 Vienna, Austria.
karl.hollaus@tuwien.ac.at

An efficient as well as an accurate simulation of the eddy currents in laminated iron cores of electrical machines and transformers is important to facilitate the design process. Modeling of each laminate requires many finite elements. The fine meshes are the reason why large equation systems arise, which may require prohibitively large amounts of computer resources to obtain an accurate solution. The multi-scale finite element method (MSFEM) has proven to overcome this restriction.

Laminated iron cores are observed as a periodic structure in the context of MSFEM. The smooth variation of the solution due to the macroscopic structure of the iron core is taken into account by standard polynomial shape functions. Orthogonal periodic micro-shape functions consider the local rough behavior of the solution caused by the microscopic structure.

Various two dimensional multi-scale formulations using a magnetic vector potential or a current vector potential are discussed. The potential formulations are either vector valued or get along with a single component. Formulations will be presented which make use of the finite element spaces $H^1, L_2, H(curl)$ and $H(div)$. Depending on the problem even or odd polynomials are used for the micro-shape functions. Particular attention is paid to the edge effect, air gaps, arbitrary penetration depths and nonlinear material properties.

Two dimensional models, i.e. no dependency in the third dimension, represent a simplification of real world problems. The case, where the current density is perpendicular to the plane of projection and its average value equals to zero is studied. This case approximates a problem which has a large but finite extension in the third dimension. Neither an application of a single component magnetic vector potential nor a use of a two component current vector potential provides the required solution. Both options only provides solutions where the average value of the current density over all laminates is zero. To overcome this shortcoming balanced currents in the individual laminates are enforced by additional conditions. This leads to a saddle point problem, the associated system is simply solved by PARDISO.

Multi-scale approaches proposed up to now do not explicitly fulfill divergence free eddy currents. A formulation will be presented which fulfills this requirement exactly. The formulation deals with the vector valued magnetic vector potential, the magnetic field is perpendicular to the plane of projection.

Numerical simulations demonstrate excellent accuracy and very low computational costs.