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# Magnetoquasistatic Multiscale Modelling of SMC Materials Using EH-Conforming Formulation and Multiharmonic Method

Janne Ruuskanen<sup>a</sup>, Innocent Niyonzima<sup>b</sup>, Alexandre Halbach<sup>a</sup>, Antoine Marteau<sup>b</sup>, Timo Tarhasaari<sup>a</sup>, Joonas Vesa<sup>a</sup>, Paavo Rasilo<sup>a</sup>, Jenni Pippuri-Mäkeläinen<sup>c</sup>

<sup>a</sup>Tampere University, Tampere, Finland

<sup>b</sup>Université Grenoble Alpes, Grenoble, France

<sup>c</sup>VTT Technical Research Centre of Finland Ltd, Espoo, Finland

Accurate designing of electrical machines made of customized materials, such as soft magnetic composites (SMC), is essential when aiming for higher energy efficiency and minimized amount of material per device. To simulate the electromagnetic behavior of SMC materials, multiscale methods are needed. In this paper, a novel multiscale approach using an **EH**-conforming formulation and multiharmonic method is presented and applied to SMC materials. Based on the simulation results, the prospects of the approach are discussed in detail.

**Keywords:** eddy current losses, multiscale modelling, soft magnetic composites

Electric devices made of materials customized for the given application can benefit from significantly higher energy efficiency than their conventional counterparts. Using more efficient customizable materials, the type and the amount of material can be optimized based on environmental sustainability.

Soft magnetic composite (SMC) materials and their manufacturing methods are one of the promising technologies for making customized materials [1]. Figure 1 shows a typical particle structure of a SMC material. The particle size in such materials can typically vary from 10 to 100  $\mu\text{m}$  in diameter.

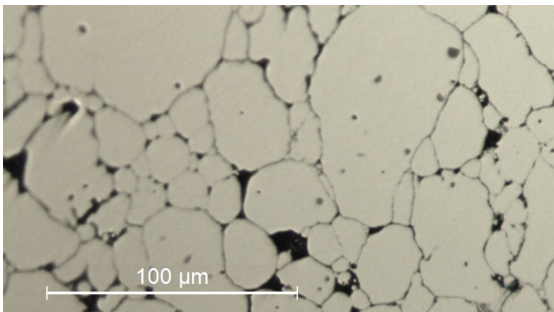


Figure 1: A microscopic image of the micro-structure of an SMC material

Modelling macroscopic entities made of such material using conventional numerical methods, such as the finite element method, can lead to infeasible problems due to large number of degrees of freedom needed to accurately interpolate e.g. the electromagnetic fields in the particle structure.

The modelling of such materials can be made feasible using multiscale methods where the computational load per computing unit is reduced by means of parallel computing and homogenization [2]. In multiscale modelling, the original problem is decomposed into one macroscopic and many microscopic problems. The macroscopic problem is formulated with homogenized microscopic quantities obtained by solving the micro-problems representing the material behavior and structure in the microscopic scale of the SMC material.

Using an adequate formulation to model the problem in hand is essential. In magnetodynamic modelling, the formulations are based on the Maxwell's magnetoquasistatic model composed of the quantities: electric field strength (**E**), electric current density (**J**), magnetic field strength (**H**) and magnetic flux density (**B**).

In magnetoquasistatics, the typical formulation type is either **B** or **H** conforming. In the multiscale setting, there are two essential mappings: the first one is from the microscopic domain  $\Omega_\mu$  to the macroscopic domain  $\Omega$  ( $\uparrow : \Omega_\mu \rightarrow \Omega$ ), and the second one is the mapping from the macro- to the micro-domain ( $\downarrow : \Omega \rightarrow \Omega_\mu$ ). Then, in the **B**-conforming formulation, **E**, **B** are mapped with  $\downarrow$  and **J**, **H** with  $\uparrow$ . On the other hand, in the **H**-conforming formulation, **J**, **H** are mapped with  $\downarrow$  and **E**, **B** with  $\uparrow$ .

In this paper, a novel multiscale formulation, an **EH**-conforming formulation, is proposed where **E**, **H** are mapped with  $\downarrow$  and **J**, **B** with  $\uparrow$ . The hypothesis is that the proposed formulation can be more suitable for multiscale modelling than the **B** or **H** conforming ones, allowing a natural way to map density fields from the microscopic scale to the macroscopic scale [3].

Furthermore, solving nonlinear time-dependent problems with time-periodic excitation using the usual time-stepping methods can be time consuming: typically multiple cycles of excitation need to be solved before reaching the steady-state solution. In this paper, as a novel contribution, the multiharmonic method [4] is applied to multiscale modelling. The hypothesis is that with the multiharmonic method, time-dependent multiscale problems with time-periodic excitation can be solved significantly faster than with time-stepping methods.

To summarize, in this paper, in order to accurately model SMC materials, a novel multiscale modelling approach based on the **EH**-conforming formulation and the multiharmonic method is presented. In order to scrutinize the prospects of the approach, magnetization and the eddy current losses are simulated in a macroscopic entity made of SMC material. The results are compared with the predictions given by the common approach using **B** and **H** conforming formulations and time-stepping methods.

## References

- [1] H. Shokrollahi, K. Janghorban, Soft magnetic composite materials (smcs), Journal of Materials Processing Technology 189 (1) (2007) 1–12.
- [2] B. Engquist, X. Li, W. Ren, E. Vanden-Eijnden, et al., Heterogeneous multiscale methods: a review, Communications in Computational Physics 2 (3) (2007) 367–450.
- [3] G. Meunier, V. Charmoille, C. Guerin, P. Labie, Y. Marechal, Homogenization for periodical electromagnetic structure: Which formulation?, IEEE Transactions on Magnetics 46 (8) (2010) 3409–3412.
- [4] D. M. Copeland, U. Langer, Domain decomposition solvers for nonlinear multiharmonic finite element equations, Journal of Numerical Mathematics 18 (3) (2010) 157–175.

\*Corresponding author : janne.ruuskanen@tuni.fi