Eddy Currents and Non-conforming Sliding Interfaces for Motion in 3D Finite Element Analysis of Electrical Machines

Stefan Böhmer, Christian Krüttgen, Björn Riemer and Kay Hameyer

Institute of Electrical Machines – RWTH Aachen University
Schinkelstraße 4, D-52062 Aachen, Germany
E-mail: Stefan.Boehmer@IEM.RWTH-Aachen.de

***Abstract*—In this paper non-conforming sliding interfaces for motion are investigated. Sliding interfaces are favourable especially for field circuit coupling in comparison to other approaches such as the Lockstep method because an arbitrary position of the rotor is possible.**

A previously presented approach by the authors [1] is extended to take eddy currents into account and to allow the extraction of lumped parameters. The sliding interfaces approach utilizes specific Lagrange multiplier to handle the relative motion between stator and rotor which require a magnetic scalar potential formulation.

I. Introduction

Numerical simulation of electrical machines requires a flexible implementation of the rotor motion in 2D and 3D models. In contrast to the well-known approaches such as Moving-Band or Lockstep method, sliding interfaces with non-conforming meshes between stator and rotor exhibit several advantages:

- No remeshing is necessary between different time steps of a transient simulation.
- Dynamic processes can be simulated with an arbitrary rotor position.

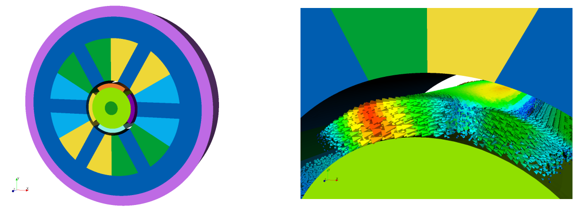
Especially the last item is crucial for field circuit coupled Finite Element (FE) simulations. In 2D FE modeling sliding interfaces can be applied for the standard magnetic vector potential formulation, whereas the required biorthogonal basis functions [2] can not be derived in a canonical way for 3D FE magnetic vector potential formulations [3], but for magnetic scalar potential formulations. In [1] the authors present a method to realize sliding interfaces by means of a magnetic scalar potential formulation for static FE simulations. For the operation of permanent magnet excited synchronous machines (PMSM) especially with surface mounted permanent magnets eddy current effects inside the magnets are not negligible. Eddy current losses have to be considered particularly if rare earth permanent magnets with comparable high electrical conductivity are applied.

In this paper the static $\mathbf{t}$-ω formulation is extended to allow for the transient computation of magnetic fields including eddy current effects in conducting regions. The employed formulation ist presented in the following section and is applied to the transient analysis of an exemplary PMSM.

II. Formulation

In magnetic scalar potential formulation the magnetic field $\mathbf{h} = \mathbf{t} - \text{grad } \omega$ is expressed by an electric vector potential $\mathbf{t}$ with $\mathbf{j} = \text{curl } \mathbf{t}$ and a single-valued magnetic scalar potential ω. In regions without eddy currents the static formulation can be applied:

$$-\text{div } (\bar{\mu}\text{grad } \omega) = -\text{div } \mathbf{b}_r - \text{div } \bar{\mu}\mathbf{t}_0. \quad (1)$$



(a) geometry (b) eddy current distribution

Fig. 1. Eddy currents in surface mounted magnets of example PMSM.

In conducting regions the magneto-quasi-static field equations can be derived from the Maxwell equations resulting in:

$$\text{curl } \frac{1}{\sigma}\text{curl } \mathbf{t} + (\partial_t \bar{\mu}\mathbf{t} - \partial_t \bar{\mu}\text{grad } \omega) = 0, \quad (2)$$

$$\text{div } (\bar{\mu}\mathbf{t} - \bar{\mu}\text{grad } \omega) = -\text{div } \mathbf{b}_r. \quad (3)$$

The required source fields $\mathbf{t}_0$ can be constructed by spanning tree techniques as illustrated in [1] and in the future also (co)homology computations should be considered [4].

III. Results

The presented formulation has been implemented in the institute's in-house FE-package *i*MOOSE [www.iem.rwth-aachen.de] and is applied to a simple PMSM testcase shown in Fig. 1(a). By the presented approach eddy current losses inside the permanent magnets can be analyzed. Fig. 1(b) shows the eddy current distribution inside the permanent magnets for a speed of $n = 4000$ rpm.

IV. Conclusion

This paper presents a quasi-static magnetic scalar potential formulation for the use with sliding interfaces to analyze motional induced eddy currents. The full paper will include details to the implemented magnetic scalar potential formulation as well as the lumped parameter extraction for a weak field circuit coupling.

References

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