

An Effective Material Approach for a Time-Commuting Magnetic Field Problem

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In this work the simulation of a time-commuting magnetic field in a laminated core is considered. For instance, the rotor of a synchronous machine is exposed to such a field during a disturbed operation. To avoid expensive computations of 3D eddy current problems of slice models with a nonlinear material a suitable effective material is introduced. With this effective material equivalent static magnetic field problems can efficiently be solved in 2D finite element models. Here, the effective material is determined by solving suitable cell problems for the case of a time-commuting magnetic field. The method with the effective material is very efficient and accurate compared to the eddy current problem as shown by numerical simulations.

Index Terms—Cell problem, eddy current problem, effective material, 2D finite element method, scalar potential.

I. INTRODUCTION

Since most of the iron sheets in an electrical machine are exposed to the same electromagnetic field distribution, the effect of magnetic stray fluxes at the axial ends can be neglected. However, a three-dimensional (3D) FE model of one slice can be still unacceptably large [1]. Although an eddy current problem (ECP) would have to be solved, a corresponding static magnetic field problem (SMFP) with a suitable effective material (EM) was considered for a 2D/1D problem in [2]. A similar approach to capture the eddy current losses and the hysteresis losses by an effective nonlinear complex permeability was investigated in [3].

Suitable cell problems (CPs) have to be defined to obtain the EM which includes both the material properties and the thickness of the sheet and the insulation layer. Losses and reactive powers are assumed to be the same in the corresponding cell problems. The CPs can be calculated with virtually no computational effort. This method with SMFP and an suitable EM is based on a scalar valued function only and requires just a 2D FE mesh for the slice problem [4].

This work focuses on a time-commuting magnetic field (TCMF), which occurs for example in a rotor during a disturbed operation. Such a field is essentially static with a small time-varying perturbation that induces eddy currents. The aim is to find a suitable EM that can be used in an equivalent SMFP and provides accurate eddy current losses generated by the TCMF. Based on reasonable assumptions an EM material can be introduced which is also valid for nonlinear iron.

First the TCMF problem is described. Then, suitable CPs are defined and the corresponding EM is calculated. To demonstrate the capability of the proposed approach to find an EM, a numerical problem with several parameters is studied.

II. COMMUTING FIELD AND METHODOLOGIES

For reasons of limited space, reference is made to [4] and only the special features of the present work are addressed.

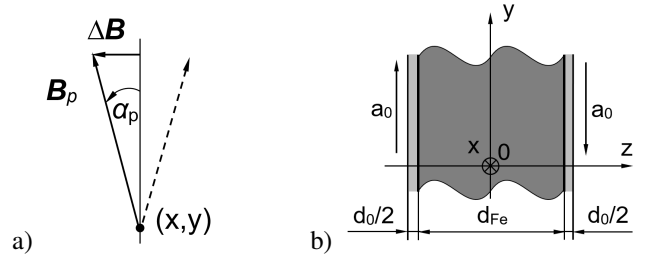


Fig. 1. a) The time-commuting magnetic flux density B_p with the selected assumption. b) One dimensional cell problem consisting of an infinite iron sheet (dark gray) and an insulation layer (light gray) excited by tangential components of the magnetic vector potential a_0 .

A. Time-Commuting Magnetic Field

The peak value of the time-commuting magnetic flux density B_p for any field point (x, y) is represented in Fig. 1, a). The angle α_p around which B_p commutes is small and B_p is assumed to be independent of z in the slice model. In order to derive an EM, the variation of the magnetic flux density ΔB needs to be reasonably quantified. To this end we select the following simple relation

$$\Delta B = B_p \sin(\alpha_p) \quad (1)$$

based on their magnitudes.

B. Cell Problems and Effective Material

The definition of the CPs and the subsequent calculation of the EM is essentially analogous to [4]. A single-component magnetic vector potential a is used for the associated ECPs and static magnetic field problems in 1D. In the present work, ΔB determines

$$a_0 = \frac{\Delta B d}{2} \quad (2)$$

for the Dirichlet boundary conditions of the CP shown in Fig. 1, b). Although B_p commutes in time, we assume that its magnitude $|B_p|$ stays constant in any field point. To calculate

$\mu_{eff}(B)$ according to Eq. (12) in [4], P and Q are the losses and the fictitious reactive powers, respectively, due to (2). Contrary to [4], B_p is used to determine $\mu(B_p)$ instead of B for the nonlinear ECs. Finally the complex-valued effective BH-curves of the EM shown in Fig. 2 can be calculated.

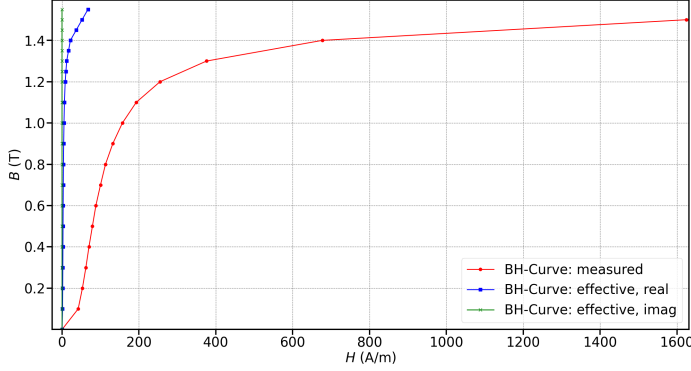


Fig. 2. Original and complex-valued effective BH-curves of the EM for $f_p=10$ Hz and $\alpha_p=10$ degrees.

III. NUMERICAL EXAMPLE

The numerical example shown in Fig. 3 is studied to evaluate the performance of the proposed method. The iron sheet is assumed to be in the xy -plane. To get the impact of a TCMF the radial component of the magnetic flux density

$$B(\varphi, t) = B_0 \sin(N_{pp}\varphi(x, y) + \alpha_p \sin(2\pi f_p t)) \quad (3)$$

is prescribed on the boundary with R . It varies with the angle φ in space, where N_{pp} represents the number of pole pairs, and commutes with the frequency f_p in time. The proposed

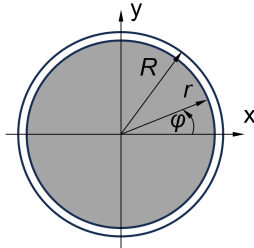


Fig. 3. Numerical example, the gray part represents the iron sheet with $r = 11.0$ mm enclosed by an air gap with an outer radius $R = 12.0$ mm.

SMFP method with the EM is compared with the ECP as a reference solution (RS). The parameters chosen for the RS are the conductivity of iron $\sigma_{Fe} = 2.08 \cdot 10^6$ S/m, the permeability of iron $\mu_{Fe}(|B|)$ based on the measured BH curve in Fig. 2 and of air $\mu_0 = 4\pi \cdot 10^{-7}$ Vs/Am, the angle $\alpha_p = 10$ degrees, the frequency $f_p = 10$ Hz, the thickness of the iron sheet $d_{Fe}=0.5$ mm, the width of the insulation layer $d_0=0.025$ mm, and the number of pole pairs $N_{pp}=2$, respectively. The corresponding effective BH-curves in Fig. 2 are used for the SMFP with EM.

Magnetic field distributions for different excitations B_0 agree well as can be seen in Fig. 4. Some results are summarized in

Tab. I. The agreement of P is satisfactory and the computation time (CT) of SFMP with EM is rather small compared to the RS.

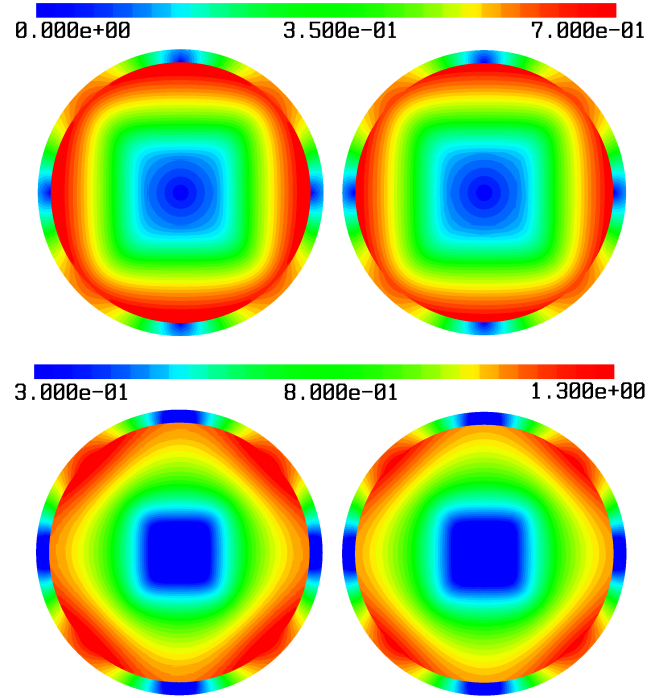


Fig. 4. Magnetic flux density distribution $|B(t = 0.4 \text{ s})|$ for $B_0 = 0.6 \text{ T}$ (above) and $B_0 = 1.2 \text{ T}$ (below), and RS (left) and EM (right), respectively.

TABLE I
RESULT DATA

B_0 T	P_{RS} μW	P_{EM} μW	ϵ_P %	NLI_{RS} -	NLI_{EM} -	CT_{RS} s	CT_{EM} s
0.6	92.93	95.40	2.66	171	8	1,675	1.68
1.2	374.6	376.7	0.57	238	15	2,364	3.01

ϵ_P the relative error in P , NLI no. nonlinear iterations, CT computation time.

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