Air Gap and Edge Effect in the 2D/1D-Method with the Magnetic Vector Potential $\boldsymbol{A}$ using MSFEM

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***Abstract*—This work presents a solution for the air gap and the edge effect in the 2D/1D-method using a magnetic vector potential. The new 2D/1D-method based on MSFEM is discussed and simulation results are presented.**

***Index Terms*—Eddy current problems, edge effect, lamination, MSFEM, magnetic vector potential $\boldsymbol{A}$, 2D/1D-method.**

I. Introduction

It is reasonable to assume that all laminates of the iron core of electrical machines are exposed to the same electromagnetic field. Therefore, it suffices to simulate only one laminate instead of the whole core. However, 3D finite element (FE) models are still too expensive [1]. To avoid 3D FE models, the problem is solved using ideas of the multiscale finite element method (MSFEM) [2] and 2D/1D-methods, which are very efficient for this specific purpose. Significant shortcomings of these methods based on the magnetic vector potential (MVP) $\boldsymbol{A}$ are the inability to consider an air gap and the edge effect in a straightforward way, [3], [4]. In case of methods using a current vector potential $\boldsymbol{T}$ considering an air gap and the edge effect are obtained almost for free [5]. For example, these improvements are relevant in simulations of material degradation due to punching etc., [6].

II. The new 2D/1D-Method with $\boldsymbol{A}$ using MSFEM

To solve the problems above also for the 2D/1D-MSFEM with the MVP $\boldsymbol{A}$, curiously, both piecewise linear micro-shape functions ϕ_1^0 and ϕ_1 are required shown in Fig. 1. The new approach for the 2D/1D-MSFEM reads as

$$\widetilde{\mathbf{A}} = (\mathbf{grad}(u_1)\phi_1^0 + \boldsymbol{A}_1\phi_1 + \mathbf{grad}(w_1\phi_1), 0)^T. \quad (1)$$

The functions u_1, $\boldsymbol{A}_1$ and w_1 depend on x and y, whereas the ϕ_i's on z. Introducing $\mathbf{grad}(u_1)\phi_1^0$ and $\mathbf{grad}(w_1\phi_1)$ allows a correct modeling of both an air gap and the edge effect.
A total magnetic flux is prescribed flowing essentially in the y-direction for the problem in Fig. 1. The old 2D/1D-method without edge effect exhibits no $\boldsymbol{J}_z$- and only a constant $\boldsymbol{J}_x$-component in the xy-plane. Without $\mathbf{grad}(u_1)\phi_1^0$ and simply using $\mathbf{grad}(w_1\phi_1)$ yields wrong components, i.e. $\boldsymbol{J}_x$ is almost zero and $\boldsymbol{J}_z$ is too big. There is a clear improvement visible in the current density distribution as shown in Fig. 2. The number of unknowns and the eddy current losses obtained by the different methods are summarized in Tab. I. The computational costs are reduced by the 2D/1D-method compared to the 3D FE model enormously.

Acknowledgment

This work was supported by the Austrian Science Fund (FWF) under Project P 27028-N15.

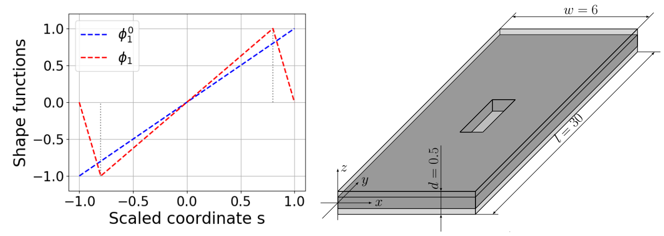

Fig. 1. Scaled shape functions (left), laminate with air gap and a hole, dimensions in mm, $\mu = 1,000\mu_0$, $\sigma = 2.08 \cdot 10^6$ S/m, f=100.0Hz (right).

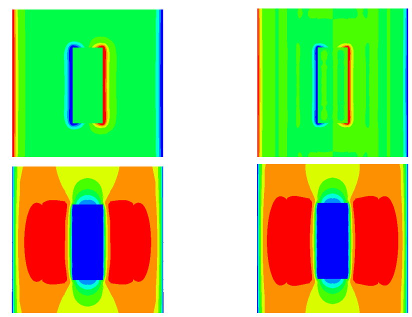

Fig. 2. Current densities around the hole in the x-y-plane, FEM3D (left) and 2D/1D new (right): $Im\{\boldsymbol{J}_z\}$ at $z = 0$ (above) and $Im\{\boldsymbol{J}_x\}$ at $z = 0.25$ (below).

TABLE I
Eddy Current Losses

FE model	NDOF H^1 of 3^{rd} order	NDOF $H(curl)$ of 2^{nd} order	Losses μW
3D FE		305,203	709
2D/1D old	4,675	9,210	718
2D/1D wrong	9,350		$115 \cdot 10^3$
2D/1D new	9,350	9,210	712

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