Simple and Cheap Structural MOR Method for the 2D/1D-MSFEM

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***Abstract*—The 2D/1D-methods based on the MSFEM reduce the simulation costs of the eddy current problem in a single iron sheet considerably compared to 3D FEM models. A new simple and cheap structural MOR method exploiting the 2D/1D-MSFEM approach is presented to reduce these costs additionally.**

***Index Terms*—Eddy current problems, lamination, structural model order reduction SMOR, multiscale finite element method MSFEM, 2D/1D-MSFEM.**

I. Introduction

Assuming that all laminates of the iron core of an electrical machine are exposed to the same electromagnetic field, it suffices to simulate only one laminate instead of the whole core. Therefore, 2D/1D-methods, [1], [2], which are based on the multiscale finite element method (MSFEM), [3], are very efficient, can be used, [4].

Although 2D/1D-MSFEMs allow rather efficient simulations the aim of this work is to reduce these computational costs essentially. Model order reduction (MOR) is applied to the model arising from MSFEM, [5]. To this end a new structural MOR (SMOR) enabled by the MSFEM approach has been developed. The SMOR preserves the structure of the multiscale approach of the original 2D/1D-MSFEM model in the reduced model.

The new SMOR, which is very cheap, is explained and some promising simulation results are presented.

II. Simple and Cheap Structural MOR Method

The approach for the 2D/1D-MSFEM using a current vector potential (CVP) $\boldsymbol{T}$ reads as

$$\widetilde{\mathbf{T}} = \begin{pmatrix} \mathbf{grad}(u_0)\phi_0 + \boldsymbol{T}_2\phi_2 + \boldsymbol{T}_4\phi_4 \\ 0 \end{pmatrix}, \qquad (1)$$

where the functions u_0, $\boldsymbol{T}_2$ and $\boldsymbol{T}_4$ depend on x and y, whereas the ϕ_i's on z as shown in Fig. 1.

Consider the finite element equation system $Ax = f$ resulting from the weak form based on (1). The simple SMOR decomposes a single snapshot x_s according to (1)

$$\begin{aligned} x_s &= (x_{u_0}, 0, 0)^T + (0, x_{\boldsymbol{T}_2}, 0)^T + (0, 0, x_{\boldsymbol{T}_4})^T \\ &= \hat{x}_{u_0} + \hat{x}_{\boldsymbol{T}_2} + \hat{x}_{\boldsymbol{T}_4} \end{aligned} \qquad (2)$$

and uses the approach

$$\hat{x} = c_0\hat{x}_{u_0} + c_2\hat{x}_{\boldsymbol{T}_2} + c_4\hat{x}_{\boldsymbol{T}_4}, \qquad (3)$$

where the x_i is a field pattern like those shown in Fig. 2, for the unknown solution $\hat{x}$. To get the constants c_i the equation system

$$\hat{x}^*_{u_0} A\hat{x} = \hat{x}^*_{u_0} f, \quad \hat{x}^*_{\boldsymbol{T}_2} A\hat{x} = \hat{x}^*_{\boldsymbol{T}_2} f, \quad \hat{x}^*_{\boldsymbol{T}_4} A\hat{x} = \hat{x}^*_{\boldsymbol{T}_4} f \qquad (4)$$

has to be solved. This is obviously very cheap.

The tangential component of the magnetic field strength for the problem in Fig. 1 is prescribed enforcing a magnetic flux flowing essentially in the y-direction.

Although the SMOR is very simple and cheap, the simulations provide reasonable results as demonstrated by Fig. 3.

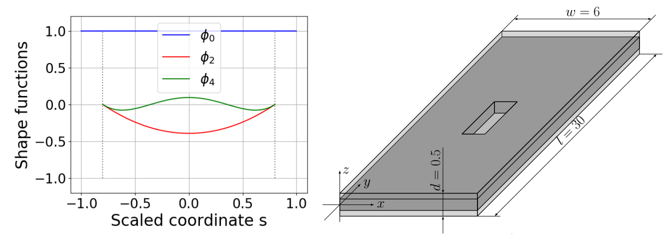

Fig. 1. Scaled shape functions with exaggerated air gap (left), laminate with air gap and a hole, dimensions in mm, $\mu = 1{,}000\mu_0$, $\sigma = 2.08 \cdot 10^6$ S/m (right).

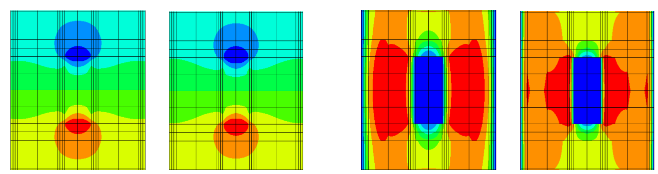

Fig. 2. Solutions for $Im\{u_0\}$ (left) and $Re\{\boldsymbol{T}_{2y}\}$ (right) at $f = 100Hz$ (first) and at $f = 10kHz$ (second).

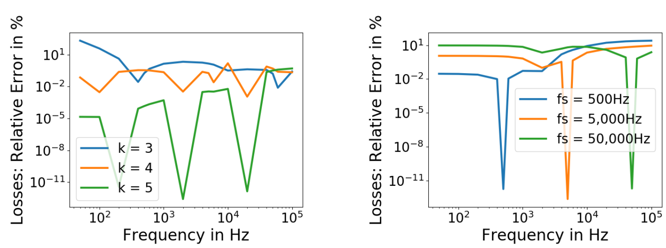

Fig. 3. Relative error: MOR with SVD and k snapshots (left), new SMOR with a single snapshot at the frequency f_s (right).

Acknowledgment

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

References

[1] O. Bottauscio and M. Chiampi, "Analysis of laminated cores through a directly coupled 2-D/1-D electromagnetic field formulation," *IEEE Trans. Magn.*, vol. 38, no. 5, pp. 2358–2360, 2002.

[2] P. Rasilo *et al.*, "Model of laminated ferromagnetic cores for loss prediction in electrical machines," *IET Electr. Power Appl.*, vol. 5, no. 7, pp. 580–588, 2011.

[3] K. Hollaus and J. Schöberl, "Some 2-D Multiscale Finite-Element Formulations for the Eddy Current Problem in Iron Laminates," *IEEE Transactions on Magnetics*, vol. 54, no. 4, pp. 1–16, April 2018.

[4] M. Schöbinger, J. Schöberl, and K. Hollaus, "MSFEM for the Linear 2D/1D-Problem of Eddy Currents in Thin Iron Sheets," *IEEE Trans. Magn., submitted., 10 pages.*, April 2018.

[5] M. Farzamfar, A. Belahcen, P. Rasilo, S. Clénet, and A. Pierquin, "Model Order Reduction of Electrical Machines With Multiple Inputs," *IEEE Trans. Ind. Appl.*, vol. 53, no. 4, pp. 3355–3360, July 2017.