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# Dilated subregions for solving FEM problems with thin air-gaps: First step, 2D magnetostatic cases

Julien FONTCHASTAGNER, Geoffrey DEVORNIQUE, Sara BAZHAR, Baptiste RISTAGNO, Denis NETTER, and Nouredine TAKORABET

*Université de Lorraine, GREEN, F-54500, Vandœuvre-lès-Nancy, France*

## Abstract

An original FEM-based method dealing with problems with thin air-gaps is proposed: thin regions are moved outside the initial domain and are dilated in order to expand the mesh size both inside and around the thin domain. Obtained 2D problems are solved thanks to an adapted formulation. Preliminary results are really encouraging.

## 1 Introduction

Many magnetic FEM problems include thin regions. Dedicated methods are abundant in the literature: for instance, techniques based on a BEM-FEM hybridization [1], on shell elements [2], or on surface conditions [3]. In the present work, a new method is introduced to solve these types of problems, more especially problems with thin air-gaps. The main interest of the proposed technique lies in its simplicity: it only needs a basic FEM solver (no coupling with BEM, or shell elements). Moreover, the user keeps the access to the unknowns (potentials) and their derivatives (fields) in the thin region, which makes it very useful for computing global quantities such as electromagnetic forces or torques.

## 2 Dilated subregion method

The main idea of our method is basic: if the whole domain (called  $\Omega$ ) contains a thin region  $\Omega_t$ , this one (eventually extended to the boundaries) is removed from  $\Omega$ , dilated by a factor  $\alpha$ , and treated separately. A schematic principle is given by Figure 1. The new problem is divided into two or three different subdomains linked by interface conditions. The dilated subregion  $\Omega_d$  is the transformation of  $\Omega_t$  by a change of coordinates  $\beta(\cdot)$ .

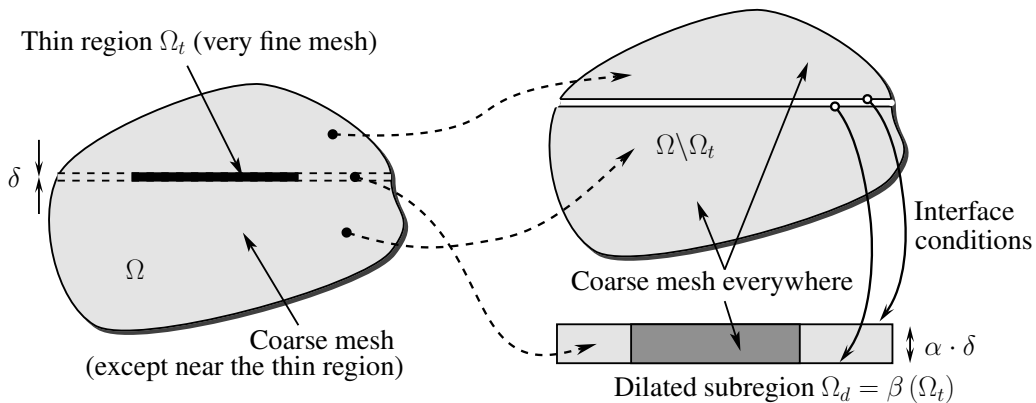


Figure 1: Schematic principle of the proposed technique

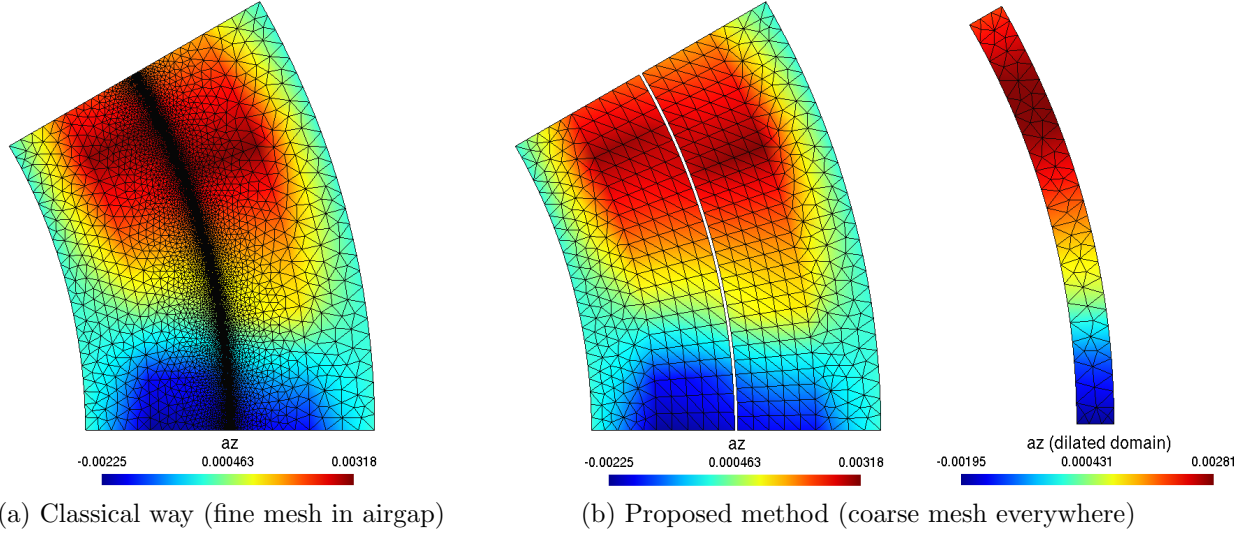


Figure 2:  $a_z$  vector potential value in a magnetic coupling

The corresponding weak form changes only in the domain  $\Omega_d = \beta(\Omega_t)$ . For example, considering a magnetic vector potential  $\mathbf{a}_z = (0, 0, a_z)$  formulation, we will show in the full paper that we can write:

$$\int_{\Omega_t} \mu^{-1} \mathbf{curl} \mathbf{a}_z \cdot \mathbf{curl} \mathbf{a}'_z \, d\Omega_t = \int_{\Omega_d} \mu^{-1} (\overline{\overline{\sigma}}_\beta \cdot \mathbf{curl}_d \mathbf{a}_z) \cdot (\overline{\overline{\sigma}}_\beta \cdot \mathbf{curl}_d \mathbf{a}'_z) |J_{\beta^{-1}}| \, d\Omega_d \quad (1)$$

where  $|J_{\beta^{-1}}|$  is the jacobian corresponding to the change of coordinates, and  $\overline{\overline{\sigma}}_\beta$  is a symmetric second order tensor which permits to express the magnetic flux density as a function of  $\mathbf{curl}_d$  (curl operator in  $\Omega_d$ ). In such a case, it can be optionally synthesized by defining an alternative reluctivity tensor in the dilated domain with:

$$\overline{\overline{\mu}}_d^{-1} = \mu^{-1} |J_{\beta^{-1}}| \overline{\overline{\sigma}}_\beta \cdot \overline{\overline{\sigma}}_\beta \quad (2)$$

Interface conditions correspond to the continuity of the potential. Our method is very easy to implement in many FEM solvers. Similar formulas are applicable with any scalar unknown and so, with any magnetostatics 2D problems. In the full paper, 2D planar or axisymmetric problems with vector or scalar potential will be detailed. The choice of the  $\alpha$  coefficient will also be discussed.

### 3 Preliminary results and conclusion

As an example, Figure 2 displays the  $a_z$  values calculated, in non-linear magnetostatics, by the classical way and the proposed method (with  $\alpha = 10$ ) on a magnetic coupling. The extremal values are exactly the same in both cases. Using a volume average of the Maxwell stress tensor in the air-gap to compute the electromagnetic torque, there is only a relative difference of 1.2% between the two problems, whereas the CPU time is divided by a factor 5. It clearly highlights the relevance and the effectiveness of our dilated subregions method.

## References

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