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Simple method to reduce computation time in planar airgap 3D FEM non-linear problems.

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In the present work, an easily implementable method to reduce CPU time for some 3D FEM problems is presented. A translational displacement between two parts on both sides of a planar airgap is taken into account with a change of coordinates in the airgap region along the z-axis. To achieve this, formulation and post processing are slightly adapted. In this digest, the proposed method is applied to an academic problem. Results are compared to a usual method. Time saving, ease of implementation and precision on preliminary results are really encouraging with a strong reduction of CPU time keeping a low relative deviation. The method could be easily applied to any configurations with planar airgap as MAGLEV, axial motor or levitation device.

Index Terms—Computation time reduction, variational formulation

I. INTRODUCTION

In 3D FEA, CPU time is a crucial issue. For multistatic problems with displacement, there are three main difficulties. The mesh has to be adapted for each position, either by fully or partially remeshing, or by applying a deformation to each element [1]. Moreover, in case of non linear material, re-using the previous solution to initialize the next iterative process is sometimes difficult. Finally, the thickness of the airgap can cause a poor quality mesh. Therefore, some methods (as shell elements [2]) are used in FEM problems including thin region. For a FEM problem with translational displacement, the proposed method deals with these difficulties by slightly adapting the weak formulation without changing the mesh. This paper can be seen as an extension of 2D dilatation method to 3D problems [3]. The main benefit of the proposed method is its ease of implementation. To move away the two parts on both sides of a planar airgap, a variable substitution is made in the airgap region along the z-axis. Keeping the mesh unchanged allows the initialization of the non-linear resolution with the previous solution. An academic problem is proposed to highlight the advantages of this method using free software Gmsh/GetDP [4][5].

II. DILATION FACTOR METHOD

The proposed method can be applied to a magnetic device with two parts (Ω_1 and Ω_2) separated by a planar airgap (Ω_e) as in Fig 1. Ω_1 has a translational displacement along the Z-Axis. With this method, the model is meshed for a constant airgap value e_d and the problem is solved for all the airgap values e_i without changing the geometry. A dilation factor α is used for each position. The constant airgap $\Omega_d(x_d, y_d, z_d)$ is the result of the dilation along the Z-Axis of the real airgap $\Omega_e(x, y, z)$ as: $x_d = x$, $y_d = y$, $z_d = \alpha z$ (see Fig. 1). The jacobian J corresponding to the change of coordinates is $|J| = \frac{1}{\alpha}$. Magnetic scalar potential (φ) formulation is used in this method. A dummy magnetic field h_s is calculated to replace the

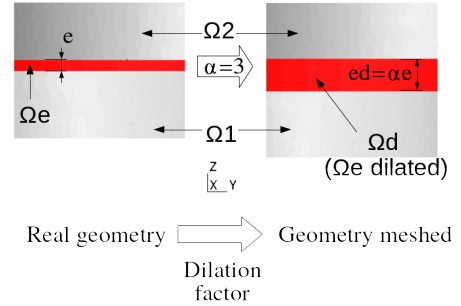


Fig. 1. Dilation along the Z-Axis.

electric current \vec{j} in the sources domain Ω_s . Without dilation, the weak formulation in the total domain Ω is:

$$\int_{\Omega_s} \mu \vec{h}_s \cdot \vec{\nabla} \varphi' d\Omega_s - \int_{\Omega} \mu \vec{\nabla} \varphi \cdot \vec{\nabla} \varphi' d\Omega = 0 \quad (1)$$

To solve another position (Ω_e) keeping the geometry (Ω_d), the gradient of φ in Ω_e has to be express as a function of the gradient of φ in Ω_d . With a symmetric second order tensor $\bar{\sigma}$:

$$\vec{\nabla} \varphi|_{\Omega_e} = \underbrace{\begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & \alpha \end{pmatrix}}_{\bar{\sigma}} \vec{\nabla} \varphi|_{\Omega_d} \quad (2)$$

Only the term corresponding to the dilated subregion is modified in the weak formulation. Considering (2) in (1) it becomes:

$$\int_{\Omega_s} \mu \vec{h}_s \cdot \vec{\nabla} \varphi' d\Omega_s - \int_{\Omega_1 \cup \Omega_2} \mu \vec{\nabla} \varphi \cdot \vec{\nabla} \varphi' d(\Omega_1 \cup \Omega_2) - \int_{\Omega_d} \mu |J| \bar{\sigma} \bar{\sigma}^T \vec{\nabla} \varphi|_{\Omega_d} \cdot \vec{\nabla} \varphi'|_{\Omega_d} d\Omega_d = 0 \quad (3)$$

Formulation and adaptation of post processing quantities will be detailed in the full paper.

III. TRANSLATIONAL DISPLACEMENT EXAMPLE

The method is illustrated with an academic problem where structured mesh is strongly difficult and is compared to a usual method meshing all positions. An axial Electromagnet with an off-centre iron plate (see Fig. 2) is chosen. The aim is to calculate the force in any directions on the iron plate for several airgap lengths.

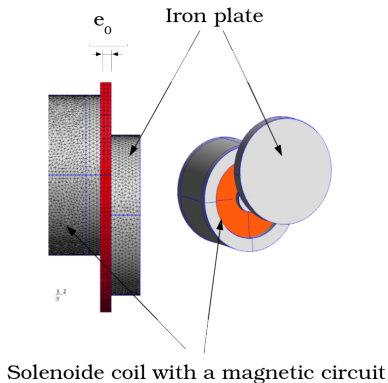


Fig. 2. Electromagnet geometry

Using our dilated subregion method, only one meshing with a given e_0 value is necessary. e_0 is chosen to have a good quality of mesh elements without expending the element number. Then the dilation factor $\alpha = \frac{e_0}{e}$ is calculated, e being the real airgap length. α is used in the weak formulation as explained in section II.

For three calculations corresponding to three airgap values (see Fig. 3) using the usual method, 3 meshes and 3 FEM resolutions are needed. Then, $\text{CPU}_{\text{Time}} = 3 \text{ Meshing}_{\text{Time}} + 3 \text{ Resolution}_{\text{Time}}$.

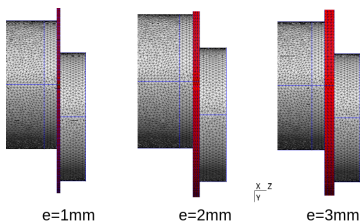


Fig. 3. Three positions with classical method

To solve the same three FEM problems using the proposed method, $e_0 = 3\text{mm}$ is chosen (as in Fig. 2) and the three factors $\alpha_i = \frac{e_0}{e_i}$ are calculated as:

- $\alpha_1 = 3/1 = 3$ to solve $e=1$ mm.
- $\alpha_2 = 3/2 = 1.5$ to solve $e=2$ mm.
- $\alpha_3 = 3/3 = 1$ to solve $e=3$ mm.

In this case, as only one position is meshed, $\text{CPU}_{\text{Time}} = \text{Meshing}_{\text{Time}} + 3 \text{ Resolution}_{\text{Time}}$.

IV. RESULTS

The problem has been solved for 100 airgap lengths with a linear and then a non-linear permeability $\mu(b)$ in iron.

TABLE I
TIME RESULTS

For Nb = 100 positions	Classical method	Dilations factors method
Linear Problem:		
Meshing Time (per unit)	1	1/Nb
Resolution Time (per unit)	1	1
Non-Linear Problem:		
Meshing Time (per unit)	1	1/Nb
Resolution Time (per unit)	1	1/7

Comparing the two methods, with and without remeshing, the maximum relative deviation on the three force components and the Co-energy is about 6% and lower than 2% in most cases. With the proposed method, only one geometry is meshed instead of 100 with the usual method both for linear and non-linear resolution. For linear problem, resolution time is the same using the two method. With the non-linear permeability $\mu(b)$, resolution time decrease using the dilation factor method. This is due to a better initialization of the iterative process. Indeed, the proposed method keeps the mesh unchanged for all positions and the non-linear resolution is initialized with the solution of the previous position. Convergence criterion is reached in 2 or 3 iterations instead of 8 and resolution time divided by 7 in this problem (time saving depends of magnetic saturation, number of mesh elements, number of positions). Time results are summarized in TABLE I.

V. CONCLUSION

Displacement has been taken into account by slightly adapting the weak formulation. The relative deviation between CoEnergy and Force is only about 6% with a reduction of CPU time. Alternative methods exist in the literature but the main benefit of the proposed method is its easy implementation keeping the mesh unchanged. It could be easily applied to any configurations with planar airgap (MAGLEV, axial motor, levitation device). And it will be applied in the full paper to an axial motor (2 rotors, 1 stator) to calculate the axial force due to unbalanced airgaps.

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