Transient Axisymmetric FVM Analysis of Electodynamic Levitation Devices

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Abstract—**In this paper a transient finite volume model for electrodynamic levitation devices analysis has been developed. Both electromagnetic and mechanical equations are time stepped and coupled to give the dynamic characteristic of the motion. Furthermore, the nonconforming mesh technique is introduced to take movement into account. To check the efficiency and accuracy of the transient FVM model, the TEAM Workshop Problem 28 is used.**

I. INTRODUCTION

The finite element method has been demonstrated as an effective tool for the transient field analysis [1-2]. Nevertheless the implementation of such models is fairly complicated. During the past few years, the finite volume method (FVM) has been proved its effectiveness in the solution of different kinds of electromagnetic problems. The FVM achieves a compromise between robustness of computation and facilities of implementation [3-4].

The discretization of devices which contains moving parts must be carefully handled. Small displacements cause a distortion of the mesh, which leads in general to a reduction of mesh quality. Large displacements require frequent remeshing of the whole device, due to the continuously changing of the position of moving parts. The unknowns on the new mesh have to be related to the unknowns on the previous mesh, therefore this causing some perturbation on the final solution [5]. In a previous work, we have developed a suitable technique based on nonconforming mesh associated to the FVM [4].

In this paper, a transient finite volume model for electrodynamic levitation devices has been developed. The displacement of the moving part is simulated thanks to the use of nonconforming mesh technique. To check the efficiency and accuracy of the developed model, the TEAM Workshop Problem 28 is analyzed. The numerical results obtained with the proposed model are then compared to measurements.

II. ANALYSIS METHOD

By using Euler's scheme, the axisymmetric governing electromagnetic equation to solve is:

$$\frac{\partial}{\partial z}\left(\frac{\nu}{r}\frac{\partial A^*}{\partial z}\right)+\frac{\partial}{\partial r}\left(\frac{\nu}{r}\frac{\partial A^*}{\partial r}\right)-\left(\frac{\sigma}{r}\frac{A^*-A^{*0}}{\Delta t}\right)=-J_{s\theta} \quad \text{in } \Omega \quad (1)$$

$$A^*=0 \quad \text{in } \Gamma \quad (2)$$

In this formulation, $A^* = r.A_\theta$ and A^{*0} are the modified magnetic vector potential at times t+Δt and t, respectively. σ is the electric conductivity, $J_{s\theta}$ is the source current density and ν is the magnetic reluctivity. The Dirichlet condition is considered by equation (2). The FVM discretization of (1) leads to the matrix system:

$$[K][A^*]=[C] \quad \text{in } \Omega \quad (3)$$

K is the coefficients matrix which characterize physical and geometrical properties of control volumes belong to Ω. C is the source vector related to the source current density $J_{s\theta}$ and A^{*0}. In order to consider the movement, the nonconforming mesh technique is used; the whole domain Ω is divided into two regions Ω1 (moving part) and Ω2 (stationary part) connected within a communication region Γ1-Γ2. Γ1 and Γ2 denotes both sides of the communication region (Fig. 1).

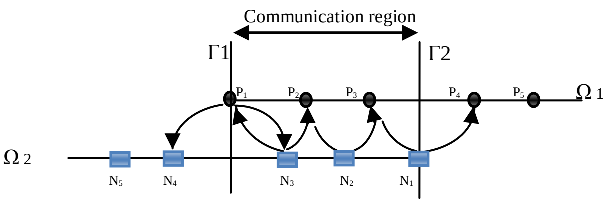


Fig. 1. Nonconforming mesh technique.
P_i: Nodes of control volumes belong to Ω1.
N_i: Nodes of control volumes belong to Ω2.

The governing equation (1) has to be integrated over each control volume belonging to Ω1 and Ω2. Therefore two algebraic systems of equations are constructed:

$$[K1][A1^*]=[C1] \quad \text{in } \Omega 1 \quad (4)$$

$$[K2][A2^*]=[C2] \quad \text{in } \Omega 2 \quad (5)$$

$A1^*$ and $A2^*$ denote the nodal values of the potential in regions Ω1 and Ω2, respectively. K1 and K2 are the coefficients matrices which characterize properties of control volumes belonging to Ω1 and Ω2, respectively. The communication between Ω1 and Ω2 can be summarized as:

Initialize $A1^* = A2^* = 0$
While $er>\varepsilon$
Calculate $A1^*$ in Ω1
Interpolate $A2^*$ in Γ2
Calculate $A2^*$ in Ω2
Interpolate $A1^*$ in Γ1
End.

III. APPLICATION AND RESULTS

To check the efficiency and the accuracy of the proposed model, the TEAM Workshop Problem 28 is used as a test problem [6]. It is made with a cylindrical aluminium plate, with σ =3.4E7S/m and m=0.107kg, installed above two cylindrical coils (Fig. 2). Both coils are connected in series, but with inverse sense of winding. All three parts are aligned coaxially. The electromagnetic repulsive force applied to the plate is produced by the interaction of the eddy current induced in the plate and the magnetic flux density.

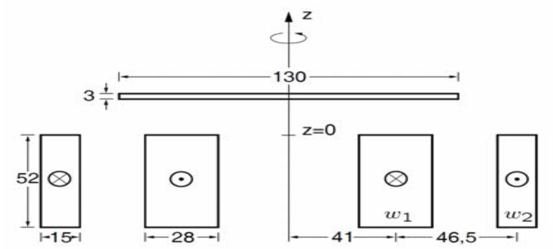


Fig. 2. Description of TEAM Workshop Problem 28.

The solution domain subject to the application of the nonconforming mesh to TEAM Problem 28 is shown in Fig. 3. The whole domain is divided into two regions connected within a communication region. The first region Ω1 denotes the moving part (plate) and the second region Ω2 denotes the stationary part (coils).

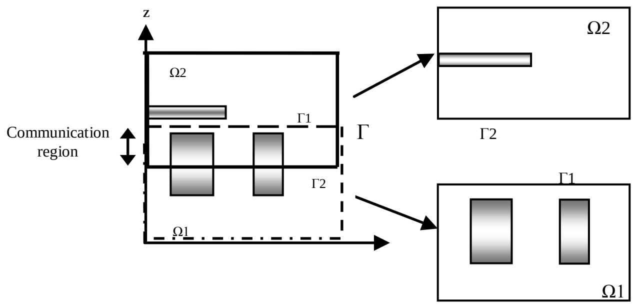


Fig. 3. Regions subject to the nonconforming mesh for test Problem.

Fig.4 shows the measured and computed values of the levitation height of the plate. A comparison between the transient FVM model and MAGNET software [7] of the repulsive force is shown in Fig. 5. It can be seen that the transient FVM model yields to good results.

IV. CONCLUSION

In this paper, the dynamic characteristic analysis of TEAM Workshop Problem 28 is performed by a transient FVM model in which both electromagnetic and mechanic equations are time stepped. The displacement of the moving part is simulated thanks to the use of nonconforming mesh technique. The validity of the proposed model is performed by comparisons with both experiments and MAGNET software results.

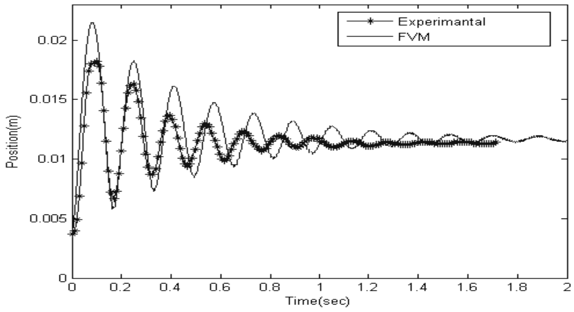
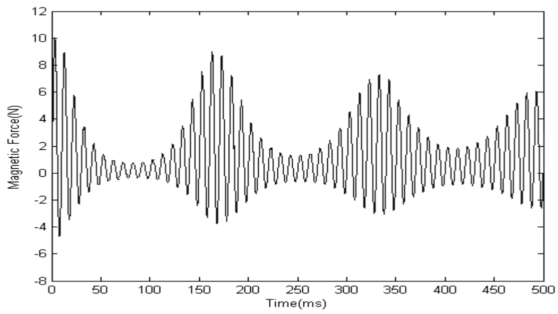
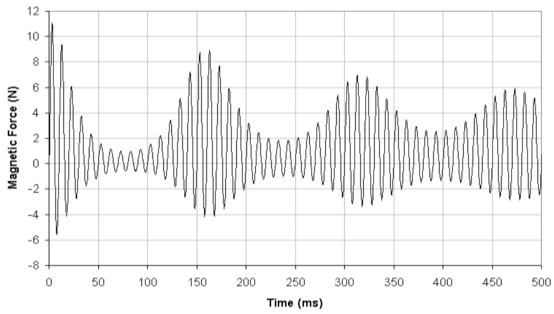


Fig. 4. Measured and computed values of the levitation height of the aluminum plate.



a)



b)

Fig. 5. The repulsive force applied to the aluminum plate, a) with the transient FVM model, b) with MAGNET software.

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