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Steady-State Analysis of an Electromagnetic Levitation Device by a New 3D Unstructured Finite Volume Method

Abstract. The standard finite volume method is featured by the simple shape of the control volume. Nevertheless, in previous works, we have demonstrated its efficiency in modeling of electromagnetic devices. On the other hand, the method consumes too much time in the case of complex geometry because the simplicity of the discretization element shape. In order to overcome this problem, we propose in this paper a new 3D unstructured finite volume method. The method is applied to solve an electromagnetic levitation problem.

Introduction

The finite volume method (FVM) is a promising method in solving electromagnetic problems such as eddy currents non destructive testing problems [1]. It is particularly attractive because features such as small required storage memory and reduced CPU time. However, in these works a simple hexahedral control volume is used (Fig.1.a). In order to handle more complex geometry, this paper proposes a new unstructured finite volume method, where the control volume is a prism element (Fig.1.b).
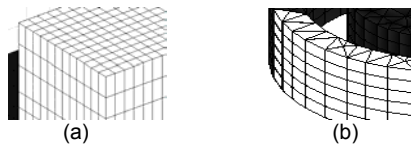

Fig.1. Control volume examples. (a) Hexahedral, (b) Prism

In order to test this new numerical tool let us consider the steady state analysis of an electromagnetic levitation device. This kind of problems is analyzed for the first time by the FVM method.

Numerical example

Fig.2.a shows the electromagnetic levitation device: TEAM Workshop problem 28 [2]. The cylindrical aluminium plate, with $\sigma=3.4E7$ and $m=0.107kg$, is installed above two cylindrical coils. The repulsive force is produced by eddy currents induced in the aluminum plate. The levitation height (hz) of the plate refers to the distance between the lower edge of the plate and the upper edge of coils ($z = 0$).
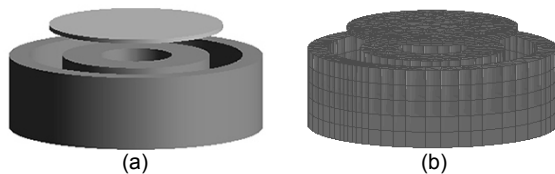

Fig.2. TEAM Workshop problem 28. (a) Description, (b) 3D mesh

The aim is to test the 3D unstructured FVM method. Thus, we do not take advantage of the axisymmetrical feature of the problem. Fig.2.b shows the FVM mesh of problem 28.

Force calculation

The upward force F_z applied to the plate is given by Lorenz law (1) where J_i denotes induced current density in the aluminum plate and B is the magnetic flux density. Equation (2) gives the forces difference to be minimized.

(1) $\qquad \mathbf{F_z} = \mathbf{J_i} \times \mathbf{B}$

(2) $\qquad \Delta\mathbf{F} = \mathbf{F_z} - \mathbf{F_p}$

If the upward force F_z is equivalent to the force of the weight (F_p) of the plate and the difference (2) must be zero.

Results

Table.1 shows a summary of the results. In this inverse problem, for each forward iteration (No. Iter) we calculate the repulsive force F_z and the estimated z position of the plate (hz). The difference ΔF, after eight iterations, is small enough and hence the iteration process is stopped. So, the aluminum plate is levitated with 11.84mm. The experimental result of the levitation high is 11.4mm [3].

No. Iter	Levitation high hz (mm)	Upward force F_z(N)
1	15	0.59
2	7.5	2.12
3	11.25	1.17
4	13.13	0.84
5	12.19	0.99
6	11.72	1.08
7	11.95	1.03
8	11.84	1.06

Table.1. Summary of numerical results

Conclusion

This paper proposes a new 3D unstructured finite volume method. To show the validity and efficiency of such a method, the TEAM Workshop problem 28 is analyzed. The proposed method yields to good results comparing with the experiment data. The unstructured FVM can be a very promising method for modeling electromagnetic problems even in the case of complex geometries.

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