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Accuracy of Advanced Energy Method for Calculating Electromagnetic Force

Norio Takahashi
Okayama University

Takayoshi Nakata
Okayama University

K. Fujiwara
Okayama University

T. Moriwake
Okayama University

ACCURACY OF ADVANCED ENERGY METHOD FOR CALCULATING ELECTROMAGNETIC FORCE

N.Takahashi, T.Nakata, K.Fujiwara and T.Moriwake
Department of Electrical Engineering, Okayama University, Okayama 700, Japan

1. Introduction

The advanced energy method[1] for calculating electromagnetic force has the following advantages:

(a) The accuracy of the advanced energy method is better than that of the conventional energy method especially when the energy does not change linearly with displacement. High accuracy can be obtained, even if the mesh is not sufficiently fine.

(b) It is not necessary to take care of the selection of integration path like Maxwell stress tensor method[2].

(c) Although the conventional energy method needs two calculations for different positions of movable body, only one calculation is sufficient for the advanced energy method[1].

In this paper, the effects of the change of energy due to displacement and the mesh refinement on the accuracy of force calculated are investigated systematically. The advanced energy method is applied to the analysis of the 3-D model for verification of force calculation, in order to compare with other methods and experiments.

2. Factors Affecting Accuracy

(1) Change of Energy due to Displacement

The effect of the change of energy due to displacement on the accuracy of force calculated is investigated using the model shown in Fig. 1, which is chosen from the standpoint that the energy does not change linearly with the gap length G. Fig. 2 shows the influence of G on the coenergy under constant current condition. When G is small, the change of coenergy in the nonlinear case is smaller than that in the linear case, and the curve approaches a straight line, because the core is saturated. Table 1 shows the y-directional components Fy of electromagnetic force which are calculated at G=0.5mm using the advanced energy method, conventional energy method and Maxwell stress tensor method. The force calculated using the conventional energy method is obtained by $(W_2-W_1)/\Delta y$. For example, in the case of Δy=0.6, W_1 and W_2 are calculated at Δy=0.2 and 0.8mm respectively. The error of the conventional energy method in the linear case is larger than that in the nonlinear case, because the coenergy in the linear case does not change linearly between $G-\Delta y/2$ and $G+\Delta y/2$. The results obtained by the conventional energy method approach that by the advanced energy method when Δy approaches zero.

(2) Mesh Refinement

The effect of the number of elements on the accuracy of force calculated is investigated using the model in which the flux distribution around the movable body is changed by the mesh refinement. Although the result obtained by Maxwell stress tensor method is fairly affected by the mesh refinement, the result obtained by the advanced energy method is scarcely affected by the mesh.

3. Force Calculation of 3-D Model for Verification

Fig. 3 shows a 3-D model for verification of force calculation. The forces calculated by the advanced energy method is compared with those by Maxwell stress tensor method, conventional energy method and magnetizing current method[3] and with experiments. The details will be shown in the full paper.

References
1. J.L.Coulomb : IEEE Trans. Magnetics, MAG-19, 6, 2514 (1983).
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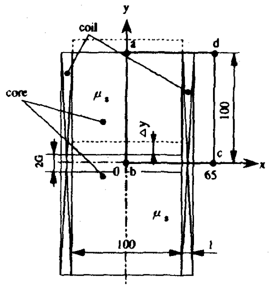

b-c-d-a : Neumann boundary
a-b : Dirichlet boundary (A =0)

Fig. 1 Model for investigating change of energy.

Table 1 Forces obtained by various methods

	calculation method		Fy ($\times 10^5$ N/m)
linear	conventional method	Δy =0.6	-2.31
		Δy =0.4	-1.95
		Δy =0.2	-1.78
	advanced method		-1.73
	Maxwell tensor method		-1.74
nonlinear	conventional method	Δy =0.6	-1.33
		Δy =0.4	-1.37
		Δy =0.2	-1.46
	advanced method		-1.47
	Maxwell tensor method		-1.47

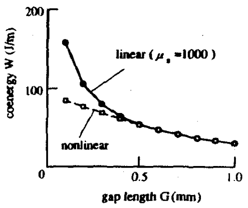

Fig. 2 Relationship between gap length G and coenergy W.

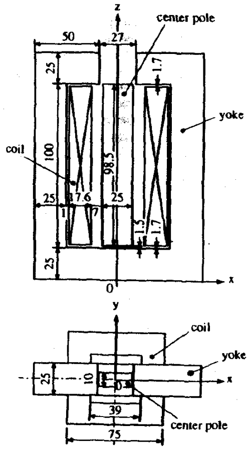

Fig. 3 3-D model for verification of force calculation.