Electrical Loss Analysis of A.C. Electromagnet Using Parallel Computing

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***Abstract*—In this paper, the electrical loss of an A.C. electromagnet is analyzed by considering the eddy current in the silicon steel sheet of the laminated cores using parallel computing. Furthermore, the effectiveness of this analysis is clarified through the comparison between the analyzed and measured results.**

***Index Terms*—3-D finite element method, A.C. electromagnet, silicon steel sheet of laminated cores, loss characteristics, parallel computing**

I. Introduction

It is desired for the optimal design of the electromagnets to clarify the electrical loss using numerical analysis. However, it is not easy to analyze the electromagnets considering the eddy current in the laminated cores, because it takes a lot of computing time and memory.

In this paper, the electrical loss of an A.C. electromagnet is analyzed by considering not only the eddy current in the laminated cores but also that in the laminated cores from the shading coil using parallel computing. Furthermore, the effectiveness of this analysis is clarified through the comparison between the analyzed and measured results.

II. Analysis Method

A. Magnetic field analysis

The fundamental equations of the magnetic field can be written by the magnetic vector potential $\boldsymbol{A}$ and the electrical scalar potential ϕ as follows [1]:

$$\mathrm{rot}\,(\nu\,\mathrm{rot}\,\boldsymbol{A}) = \boldsymbol{J}_0 + \boldsymbol{J}_e \tag{1}$$

$$\boldsymbol{J}_e = -\sigma\left(\frac{\partial \boldsymbol{A}}{\partial t} + \mathrm{grad}\phi\right), \mathrm{div}\boldsymbol{J}_e = 0 \tag{2}$$

where ν is the reluctivity, $\boldsymbol{J}_0$ is the exciting current density, $\boldsymbol{J}_e$ is the eddy current density, and σ is the electrical conductivity.

The detail of parallel computing for the magnetic field analysis coupled with the voltage equation is described in [2].

B. Electrical loss calculation

The hysteresis loss is estimated by time variations of the calculated flux density [3].

When the lamination is taken into account, the eddy current loss W_{ed} in the shading coil and the silicon steel sheet of the laminated cores is given as follows:

$$W_{ed} = \frac{1}{\tau}\int_t^{t+\tau}\left\{\int_{V_e}\frac{(\boldsymbol{J}_e)^2}{\sigma}dV\right\}dt \tag{3}$$

where τ is the time period of the eddy current waveform, and V_e is the region of the conductor with the eddy current.

When the lamination is not taken into account, the eddy current loss in the cores is estimated by time variations of the calculated flux density [3].

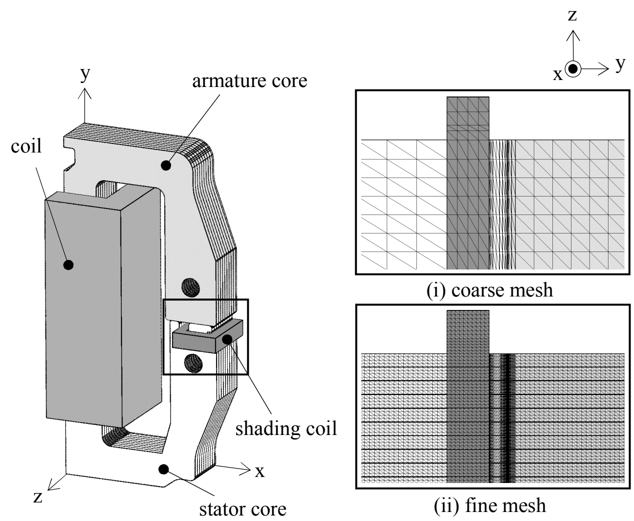
III. Analyzed Model and Conditions

Fig. 1 shows the analyzed model. The analyzed region is 1/4 of the whole region because of symmetry.

In this paper, the electrical loss of the A.C. electromagnet is analyzed using the coarse 3-D finite element mesh and the fine one under the condition that the sinusoidal voltage is applied to the coil when the armature and the stator is closed. When the fine mesh is used, the lamination of the armature and the stator cores is taken into account, and the eddy current is considered not only in the shading coil but also in the laminated cores. On the other hand, when the coarse mesh is used, the lamination of the cores is not taken into account, and the eddy loss in the core is estimated by time variations of the calculated flux density.

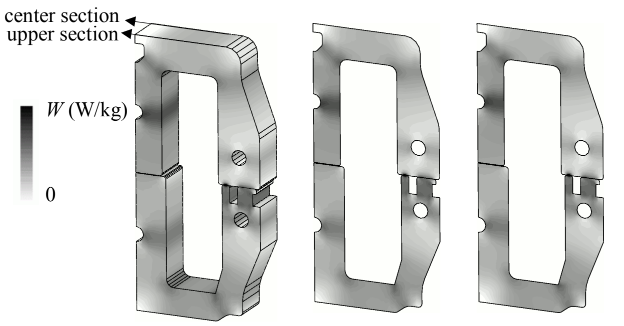
IV. Results and Discussion

Fig. 2 shows the distribution of the eddy current loss of the cores. When the lamination is not taken into account, there is little difference of the distribution between the upper and the center section and that between the armature and the stator core.



(a) overall view (b) finite element meshes

Fig. 1. Analyzed model.



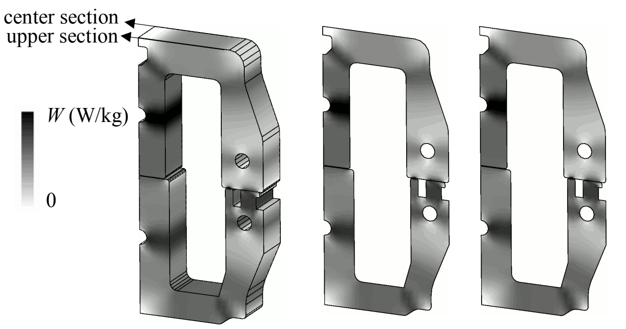
(i) overall view (ii) upper section (iii) center section (z = 0 mm)

(a) coarse mesh (without lamination)

(i) overall view (ii) upper section (iii) center section (z = 0 mm)

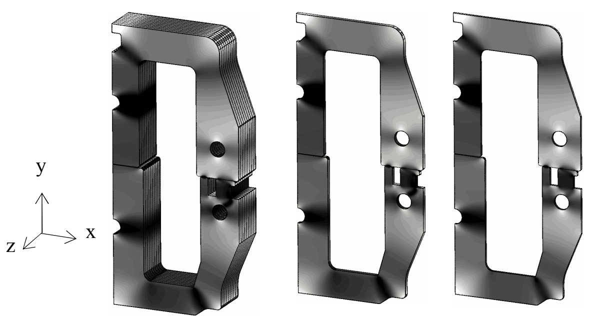
(b) fine mesh (with lamination)

Fig. 2. Distributions of eddy current loss of cores.



(i) overall view (ii) upper section (iii) center section (z = 0 mm)

(a) coarse mesh



(i) overall view (ii) upper section (iii) center section (z = 0 mm)

(b) fine mesh

Fig. 3. Distributions of hysteresis loss.

On the other hand, when the lamination is taken into account, there is a difference of the distribution between the upper and the center section. Especially, the distribution is concentrated at the stator core. This is due to the eddy current flow from the shading coil into the laminated cores.

Fig. 3 shows the distribution of the hysteresis loss. Regardless of whether the lamination is taken into account or not, the distribution between the upper and the center section and that between the armature and the stator cores show the similar tendency.

Fig. 4 shows the loss characteristic, which are normalized by the value of measured results. The copper loss and the eddy current loss of the shading coil are dominant in the electrical loss. The discrepancy between the calculated and the measured electrical loss becomes small by taking into account the lamination.

Table I shows the discretization data and CPU time.

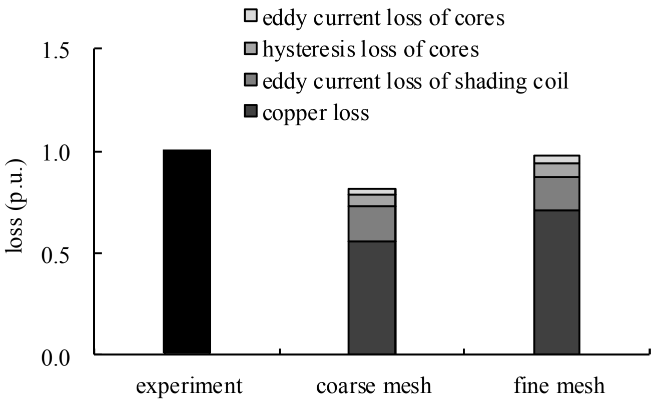


Fig. 4. Loss characteristics.

TABLE I
DISCRETIZATION DATA AND CPU TIME

	Coarse mesh	Fine mesh
Number of elements	435,675	10,153,998
Number of nodes	77,090	1,725,444
Number of edges	521,548	11,945,203
Number of time steps	144 (total) 36 (1 cycle)	
CPU time (hours)	15.9*1	100.7*2

Computer used : *1Intel Core i7 (3.40GHz)
*2Intel Core i7 (3.40GHz)*16

REFERENCES

[1] S. Ito and Y. Kawase, *Computer Aided Engineering of Electric and Electronic Apparatus Using Finite Element Method*, Morikita Publishing Co., 2000 (Japan).

[2] T. Nakano, Y. Kawase, T. Yamaguchi, M. Nakamura, N. Nishikawa, and H. Uehara: "Parallel Computing of Magnetic Field Analysis for Rotating Machines Driven by Voltage Source on the Earth Simulator", *IEEJ Trans.*, Vol.131-D, No.10, pp. 1212-1216 (2011).

[3] K. Yamazaki: "Efficiency analysis of induction motors for ammonia compressors considering stray load losses caused by stator and rotor slot ripple" *Conference Record of the 2001 IEEE Industry Applications Conference 36th Annual Meeting*, Vol.2, pp. 762-769, 2001.