Examination of Eddy Current in Laminated Core without Insulation

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Abstract —In the laminated core of transformer, motor, etc., each electrical steel sheet is usually insulated in order to reduce the eddy current loss. It is reported that the insulation is not necessary in such laminated core in some condition. But, the report about the quantitative and systematic examination of the relationship between the insulation and eddy current is few. In this paper, the eddy current losses of core made of SPCC (colded rolled steel sheets) of different widths with and without insulation under various conditions are analyzed. It is shown that the increase of eddy current is affected by the ratio of the resistance of steel and the contact resistance.

I. INTRODUCTION

It is reported that the eddy current loss of the segmented Nd-Fe-B sintered magnet can be reduced even if magnets are not insulated [1]. Due to the same reason, the insulation is not necessary in the laminated core in some condition. But, the mechanism of such phenomenon and a criterion for omitting the insulation is not clear.

In this paper, the behavior of the eddy currents between plates without insulation is analyzed using the measured contact resistance between steels. The equivalent circuit for such a laminated core without insulation is examined. As a result, a criterion to determine the necessity of insulation is proposed.

II. EDDY CURRENT IN LAMINATED CORE WITHOUT INSULATION

We measured the contact resistance R’ between SPCC steels. Table I show the relationship between the impressed force F, conductivity of contact part σ’ and the contact resistance coefficient K[1]. The eddy current analysis considering the resistance of the contact part in the laminated core shown in Fig.1 is carried out using the 3-D finite elements method (FEM). The SPCC steel plate (thickness: 0.5mm) is laminated. The frequency is chosen as 0.001Hz in order to avoid the skin effect. The magnetic field is impressed in the y-direction.

Fig.2 shows the eddy current distribution in the laminated core without insulation (areas α and β in Fig.1) when the conductivity σ’ of the contact part is equal to 10.7S/m and the width W of core is equal to 150mm. In this case, the eddy current loss is increased to about 7 times of that with insulation.

TABLE I
FORCE *F*, CONDUCTIVITY OF CONTACT PART σ’ AND CONTACT RESISTANCE COEFFICIENT *K* (SPCC)

F [MPa]	σ′ [S/m]	*K* [$\times 10^{-7}\,\Omega\,m^2$]
6	10.7	9.33
15	14.6	6.86
30	21.5	4.66
45	29.6	3.38
60	38.2	2.62
75	50.4	1.98
90	68.9	1.45

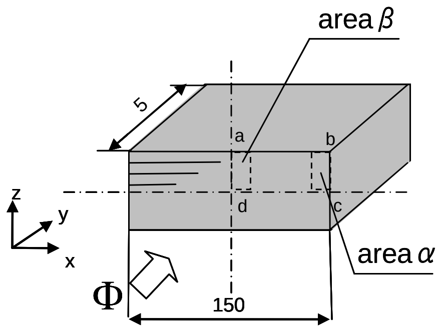
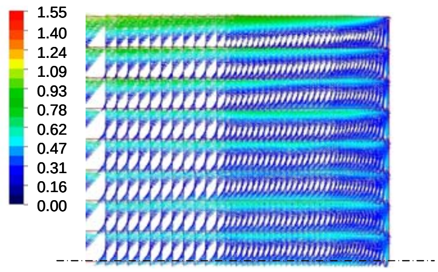
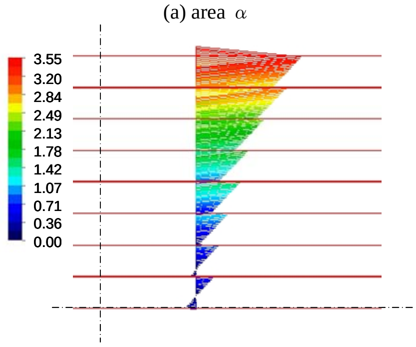


Fig.1. Model of laminated core.



(a) area α



(b) area β

Fig.2 Eddy current distribution (*Bm*=0.5T, *f*=0.001Hz, *W*=150mm, σ’=10.7S/m), area α in Fig.1.

III. PROPOSAL OF EQUIVALENT CIRCUIT AND CRITERION

From the eddy current analysis, it can be found that the magnetic circuit can be represented by an equivalent circuit (ECM) shown in Fig.3. The resistance R in the steel and the resistance R' of the contact part are written as follows using the cross sectional areas S_1, S_2, etc. in Fig.3(b);

$$R = \frac{W}{\sigma S_1} \tag{1}$$

$$R' = \frac{K}{\frac{S_2}{2}} = \frac{2K}{S_2} \tag{2}$$

The increase coefficient η of the eddy current loss is defined by

$$\eta = \frac{W_e}{W_{e0}} \tag{3}$$

where, We is the eddy current loss in the laminated core without insulation, We_0 is that with insulation. η can be represented using the ratio α defined by the following equation;

$$\alpha = \frac{R}{R'} = \frac{1}{2\sigma}\frac{WS_2}{KS_1} \tag{4}$$

In the case of the equivalent circuit of the laminated core with 16 sheets, η can be given by the following equation:

$$\eta = \frac{A_1}{A_2} \tag{5}$$

$$A_1 = 2(16384 + 80896\alpha + 167424\alpha^2 + 188032\alpha^3 + 123840\alpha^4 + 48152\alpha^5 + 10524\alpha^6 + 1135\alpha^7 + 43\alpha^8) \tag{6}$$

$$A_2 = 32768 + 131072\alpha + 212992\alpha^2 + 180224\alpha^3 + 84480\alpha^4 + 21504\alpha^5 + 2688\alpha^6 + 128\alpha^7 + \alpha^8 \tag{7}$$

Table II shows the relationship between the ratio α and the increase coefficient η for the case of W =10mm as an example. The results of 5mm-150mm in Fig.4 shows the increase coefficient η calculated by FEM. The figure denotes that the model of ECM is appropriate, and the increase of eddy current loss due to the eddy current flowing between sheets can be discussed using the ratio α. We can understand that the eddy current loss increases about 20% when α equal to 0.2. The ratio α is can be considered as an criterion for the judgment of insulation.

We also conceived a line element or surface element like the gap element and shield element [2] for treating easily the contact part. The details will be shown in the full paper.

IV. REFERENCES

[1] N. Takahashi, H. Shinagawa, D. Miyagi, Y. Doi, K. Miyata : "Analysis of eddy current losses of segmented Nd-Fe-B sintered magnets considering contact resistance" , IEEE Trans. on Magn., vol.45, no.3, pp.1234-1237, 2009.

[2] T. Nakata, N. Takahashi, K. Fujiwara. and Y.shiraki : "3-D magnetic field analysis using special elements", IEEE Trans. on Magn. vol.26, no.5, pp.2379-2381, 1990.

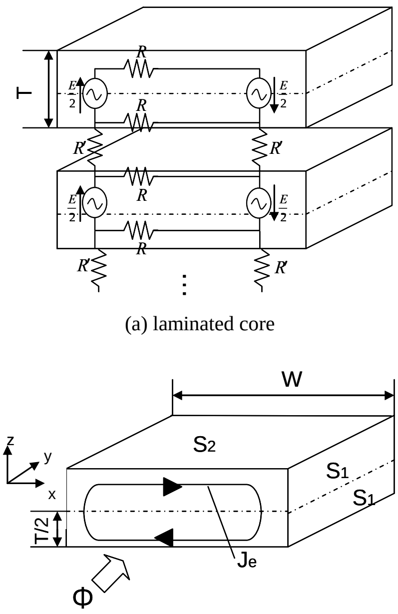


Fig.3 Resistances in steel and contacting part.

TABLE II
CONTACT RESISTANCE R', SPECIFIC RESISTANCE R, COEFFICIENT η, CRITERION α (SPCC).

σ'[S/m]	R'[Ω]	R[Ω]	η	α
1.00	0.024	1.01E-03	1.04	0.04
5.00	0.0048	1.01E-03	1.20	0.21
10.00	0.0024	1.01E-03	1.40	0.42

(n = 16, f = 0.001Hz, W = 10mm)

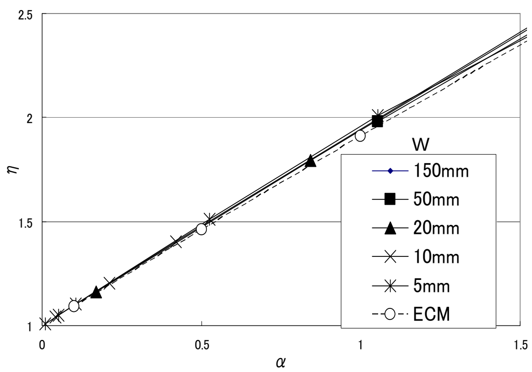


Fig.4 Relationship between ratio α and increase coefficient η.