The Iron Loss Error Comparison of IPMSM according to Fitting Function

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***Abstract*—In this paper, a new calculation method of iron loss coefficients is proposed by the Steinmetz equation from Epstein data. The iron loss coefficients were defined as a function of the magnetic flux density, and the calculation method of iron loss coefficients was proposed by Boltzmann function, etc. The calculation results and experimental value were analyzed and compared.**

***Index Terms*—Permanent magnet motors, Magnetic losses, Hysteresis, Eddy currents, Loss measurement, Ferrimagnetic materials.**

I. Introduction

Although 100 years has been passed since the formulation for iron loss had defined by Steinmetz for the first time, the research on iron loss is still ongoing[1]. That is why the previous iron loss coefficients are hard to be applied to recent ferromagnetic material because the increased residual magnetic flux density of the Permanent Magnet(PM) and the iron core material characteristics improves[2]. Until now, the Steinmetz constant n was assumed an unknown parameter when the iron loss coefficients were calculated. In this paper, it was fixed as 2, and the other coefficients were calculated. And the new calculation method of the iron loss coefficients was shown as the function of magnetic flux density in this paper.

The calculating method according to fitting function of iron loss coefficients in Interior Permanent Magnet Synchronous Motor(IPMSM) of 600(W) was proposed. Accordingly, the result of a calculation and experimental value were analyzed and compared.

II. The Previous Method of Iron Loss Coefficients Calculation

In this paper, the specifications of applied model are described in Table I.

TABLE I
SPECIFICATIONS OF THE APPLIED MODEL

Item	Specification
Material : stator & rotor	50PN1300
Output Power(W)	600
Pole/Slot	8/12
Rated Speed(rpm)	3000
Operating Frequency(Hz)	200
Br(T)	1.3
Stack Length(mm)	45
Stator Diameter(mm)	83.6
Phase Resistance(ohm)	0.0235

In the previous method of iron loss coefficients calculation, the Steinmetz constant was fixed at 2[3]. Because, the magnetic flux density was increased by improvement of the PM and iron core material in electrical machine. In conclusion, the numerical formula of iron loss can be obtained by (1).

$$W_i = W_h + W_e + W_a = k_h f B_m{}^2 + k_e f^2 B_m{}^2 + k_a f^{1.5} B_m{}^{1.5} \quad (1)$$

The Curve Fitting Method(CFM) and iron loss calculation of IPMSM were performed on the basis of the provided Epstein data. The results are shown in Table II.

TABLE II
IRON LOSS CALCULATION RESULTS OF THE PREVIOUS METHOD

(Hz)	W_h(W)	W_e(W)	W_a(W)	Wi(W)cal	Wi(W)exp	W_h(%)	W_e(%)	W_a(%)
50	2.76	1.30	0.84	4.90	3.02	56.27	26.57	17.14
60	3.24	1.83	0.96	6.05	5.46	53.64	30.41	15.95
100	5.10	4.82	1.41	11.33	9.30	44.96	42.53	12.50
120	5.99	6.80	1.62	14.41	13.88	41.54	47.17	11.27
150	7.29	10.36	1.92	19.58	19.04	37.26	52.91	9.81
200	9.41	17.83	2.38	29.62	28.35	31.76	60.18	8.05
250	11.47	27.16	2.82	41.45	39.57	27.66	65.53	6.81
300	13.47	38.32	3.24	55.03	57.04	24.48	69.63	5.88

W_i(W)cal : calculation data, W_i(W)exp : experimental data

As the results of calculated with previous method, hysteresis loss ratio and eddy current lass ratio were similarly calculated in comparison usually known loss ratio.

Total iron loss obtained satisfactory results at the rated speed having error of 4.4% compared to the experimental value. But the following errors were occurred with the existing calculation method.

First, the abnormal eddy current loss ratio is uniformly decreasing according to an increase of the frequency.

Second, W_h / f should be a constant value according to the increase of the frequency[4]. But, W_h / f is reducing.

In order to complement the above two problems, the iron loss coefficients were expressed as function of magnetic flux density in this paper. And the iron loss coefficients were calculated by using the different fitting-functions.

III. The Proposed Method of Iron Loss Coefficients Calculation

The iron loss coefficients were estimated by each magnetic flux density through the Epstein data of electrical steel 50PN1300[5]. The results can be expressed as Fig. 1.

$$\frac{W_i}{f} = k_h B_m^2 + k_e B_m^2 f + k_a B_m^{1.5} \sqrt{f} \quad (2)$$

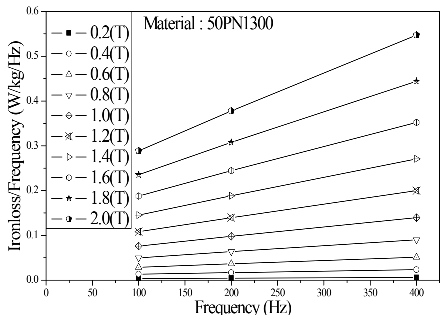


Fig. 1. The result of iron loss according to frequency at each magnetic flux density

In this paper, the iron loss coefficients were estimated by using Fig. 1 and (2). And the estimated iron loss coefficients were indicated about magnetic flux density by using 4 different fitting-functions, as (3)~(6).

$$k_i = k_{i_0} + k_{i_1} \cdot B_m + k_{i_2} \cdot B_m{}^2 + k_{i_3} \cdot B_m{}^3 \quad (3)$$

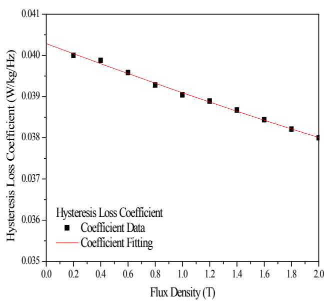
$$k_i = \frac{A_1 - A_2}{1 + e^{(B_m - x_0)/dx}} + A_2 \quad (4)$$

$$k_i = y_0 + A_1(1 - e^{-B_m/t_1}) + A_2(1 - e^{-B_m/t_2}) \quad (5)$$

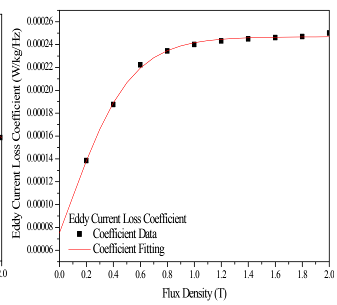
$$k_i = a - b \cdot \ln(B_m + c) \quad (6)$$

where,

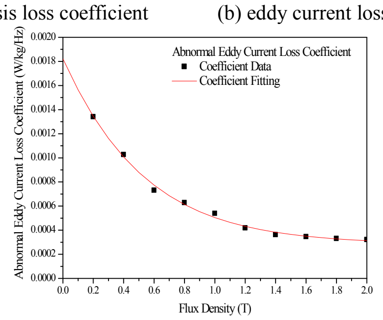
$$k_i = k_h,\ k_e,\ k_a$$



(a) hysteresis loss coefficient



(b) eddy current loss coefficient



(c) abnormal eddy current loss coefficient

Fig. 2. Iron loss coefficients calculation according to flux density (Boltzmann function)

Equation (3) is a cubic function, (4) is a Boltzmann function, (5) is an exponential function and (6) is a logarithm function against magnetic flux density.

The loss coefficients of Boltzmann function can be shown in Fig. 2, when each coefficient of (3)~(6) were estimated as magnetic flux density.

The iron loss coefficients calculation results of 4 different fitting-functions are shown in all the same pattern. For lack of space, the calculated results of the Boltzmann function were only expressed in Table III.

TABLE III
IRON LOSS CALCULATION AND THE EXPERIMENTAL RESULTS (BOLTZMAN FUNCTION)

(Hz)	W_h(W)	W_e(W)	W_a(W)	Wi(W)cal	Wi(W)exp	W_h(%)	W_e(%)	W_a(%)
50	2.69	0.90	0.44	4.06	3.02	66.66	22.36	10.98
60	3.23	1.30	0.58	5.15	5.46	63.17	25.43	11.40
100	5.39	3.62	1.26	10.33	9.30	52.52	35.24	12.23
120	6.47	5.21	1.65	13.42	13.88	48.54	39.08	12.38
150	8.08	8.14	2.31	18.68	19.04	43.63	43.92	12.45
200	10.78	14.47	3.55	29.06	28.35	37.43	50.24	12.33
250	13.48	22.98	5.00	41.45	39.57	32.51	55.43	12.06
300	16.17	33.09	6.57	55.83	57.04	28.97	59.26	11.77

W_i(W)cal : calculation data, W_i(W)exp : experimental data

IV. CONCLUSION

As a iron loss calculation results, the comparison of the previous and the proposed method are practically same[4]. But, the composition ratio of each iron loss appeared an entirely different result, as shown in Table II, III. The analysis and comparison will be discussed in more detail in full-paper.

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