Improvements in Accuracy of Anomalous Eddy Current Loss Calculations（2）

Overview

The iron loss analysis method the most commonly applied uses measured iron loss data (hereinafter referred to as the conventional method). In the conventional method, since the application range is limited to the measurement conditions, there were problems in evaluating the influence of harmonics and DC superposition. On the other hand, new models such as play models [1] [2] [3] and 1D methods [4] [5], have come to be applied to iron loss analysis (hereinafter referred to as new methods). However, even with these new methods they still won't be able to take in account the anomalous eddy current loss.

The previous report [6] showed a method applicable to transient calculation as a modeling method of anomalous eddy current loss. The challenge of this method, has been a problem of physical interpretation of fitting by a function of anomalous eddy current loss correction coefficient, and a coefficient of less than 1 in a high frequency region. In this paper, as a result of examining and applying a new modeling method of anomalous eddy current loss, it is possible to obtain anomalous eddy current loss according to the excitation state. However, it was found that when applied to a high-frequency, high-DC bias field with large deviation from the excitation state at the time of derivation, it deviates from the actual measurement. It was confirmed that the iron loss due to the waveform including the harmonics can be calculated with high accuracy under the condition that the frequency is 1 kHz or less and the direct current superimposed amount is not large.

1. Anomalous eddy current loss calculation method in high accuracy iron loss analysis method

Anomalous eddy current loss was obtained by separating components from the measured iron loss value in the conventional method. However, in the new method, the anomalous eddy current loss is determined by simulation. A method often used for practical convenience is to consider anomalous eddy current loss as a correction factor for classical eddy current loss [7]. However, the conventional anomalous eddy current loss coefficient identification has the following problems.

- It applies the value identified at low frequency in the entire frequency range.
- Skin effect is not considered in the classical eddy current loss at the time of identification

Therefore, in this white paper, we attempted to improve the anomalous eddy current loss coefficient by the following method:

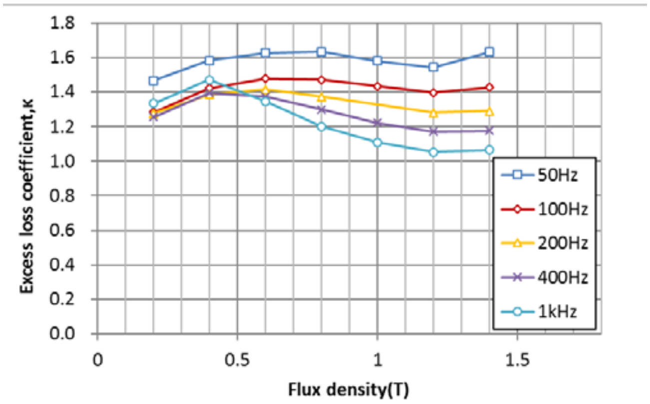
- Coefficients are identified for each operating point
- At the time of identification, the hysteresis loss is calculated using the play model, and classical eddy current loss is calculated using the 1D method

Table 1 shows the improvement of the method, Fig. 1 shows the excitation magnetic flux density amplitude obtained by this method, and the anomalous eddy current loss coefficient for each frequency. It can be observed that it changes with respect to the magnetic flux density and that it changes with increasing frequency after decreasing.

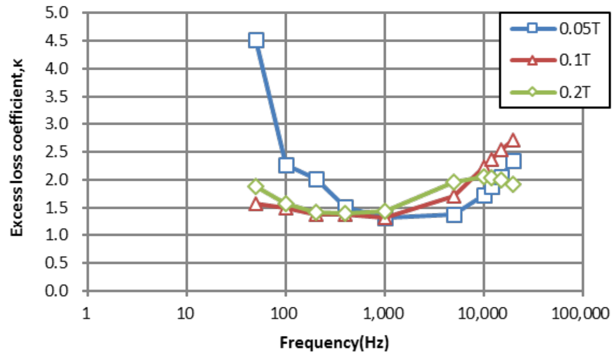
This white paper uses this method to calculate the core loss for a magnetic flux density waveform including harmonics, and reports the results comparing it with actual measurements. We will also explain the application scope of this method.

Table 1 Improvement points of anomalous eddy current loss

	Current method	Improvement method
Drive state dependency	Constant	Coefficient calculation
Anomalous eddy current loss calculation method	Anomalous eddy current loss = Iron loss - Hysteresis loss - Classical eddy current loss	
Iron loss	Measurement value Use	
Hysteresis loss	Separate two-frequency method	Calculated by magnetic field analysis using play model with calculate
Classical eddy current loss eddy current loss	Without skin effect at low frequency Calculate eddy current loss by	Magnetic field analysis



(a) Magnetic flux density amplitude dependency (frequency 50 Hz-1 kHz)



(b) Frequency dependency (amplitude 0.05 T-0.2 T)

Fig. 1 Anomalous eddy current loss coefficient (35A360)

Iron loss is 0.05 to 1.4 T, 50 Hz to 20 kHz the measurement was performed in the range of

2. Verification of high accuracy iron loss analysis method including anomalous eddy current loss [8]

2.1 Evaluation of error at the time of direct current superposition

The purpose of the proposed method is to improve the accuracy of iron loss calculation for any waveform, such as the superposition of harmonics on the fundamental wave or the superposition of direct currents on the harmonics. However, as shown in 1, the proposed method identifies an anomalous eddy current loss coefficient in sinusoidal magnetic flux density excitation without direct current superposition. Therefore, it is not clear whether this anomalous eddy current loss coefficient can be applied to a fundamental wave or a harmonic superimposed on a direct current. Therefore, in order to verify the proposed method and evaluate the error, we measured the loss in the state in which the direct current is superimposed on the harmonic and compared it with the proposed method. Specifically, as shown in Fig. 2, a measurement was performed in which a direct current B_c is superimposed on the alternating current of amplitude B_m. The measurement was performed while changing the direct current superimposed amount B_c. In addition, since the ratio of hysteresis loss, eddy current loss, and anomalous eddy current loss changes depending on the frequency, measurement was also performed by changing the AC frequency. The measurement conditions are shown in Table 2. The sample used was 35A210 for its large ratio of anomalous eddy current loss among non-oriented electrical steel sheets.

A comparison of the results of the measurement (Measurement), the conventional iron loss calculation method (Conv.) based on the Steinmetz method, and the proposed method (Propose) on the direct current superimposed loss amount is shown in Fig. 3. Below 1 kHz, the error does not increase in the proposed method even if the amount of DC bias increases. The conventional method which does not consider the DC superimposed state has a large error around 1.5T. On the other hand, the proposed method overestimates the loss if the DC bias amount is increased at 5 kHz or more. This indicates that the anomalous eddy current loss coefficient identified in the state without direct current superposition is too large for direct current superposition of 1 T or more. Hysteresis loss and eddy current loss are calculated by the play model in proposed method and eddy current calculation from the measured value of DC superposition, and the result of estimating the anomalous eddy current loss coefficient is shown in Fig. 4. The factor approaches 1 at high frequency and high DC superposition, suggesting that the anomalous eddy current loss is extremely small with respect to the eddy current loss in the high DC superposition state. The examination was conducted with 50A 470 with small anomalous eddy current loss, and the tendency was similar.

In this way, the proposed method is much more accurate than the conventional iron loss calculation method even in the DC superimposed state at 1 kHz or less. On the other hand, application to the direct current superposition state at a high frequency of 5 kHz or more remains a challenge.

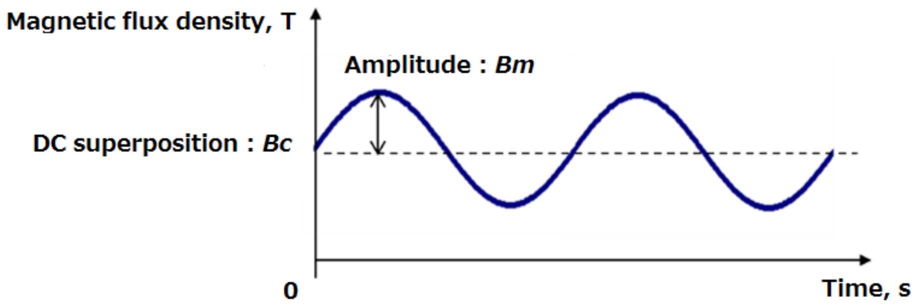
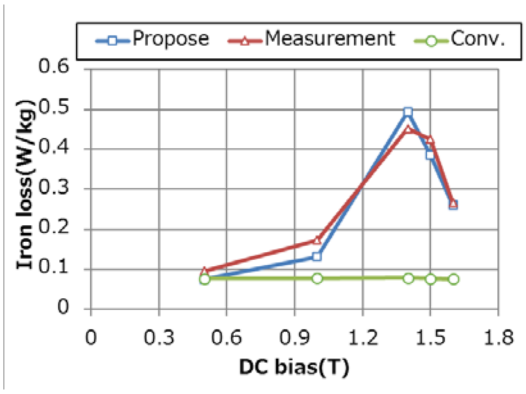


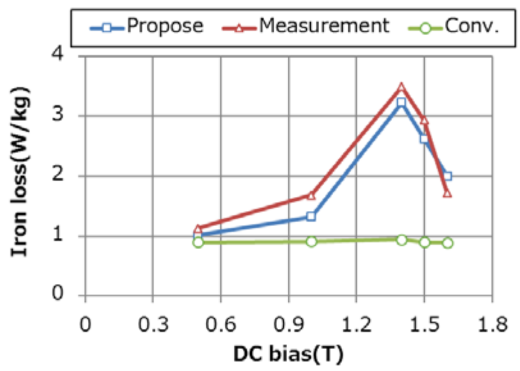
Fig. 2 Outline of DC superposition measurement

Table 2 DC superposition measurement condition

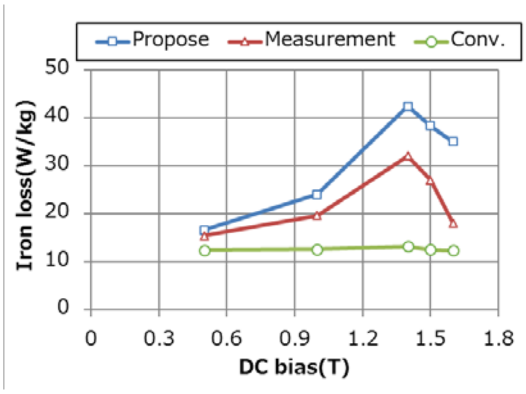
	value
DC superposition amount B_c, T	0.5, 1, 1.4, 1.5, 1.6
AC amplitude B_m, T	0.1
AC frequency, Hz	200, 1000 , 5000, 10,000



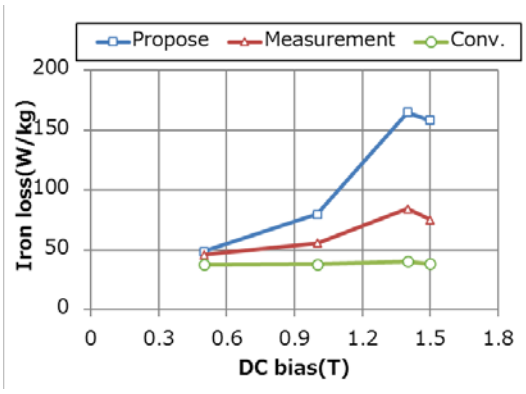
(a) 200Hz



(b) 1 kHz



(a) 5 kHz



(b) 10 kHz

Fig. 3 Comparison of measurement and analysis at direct current superposition

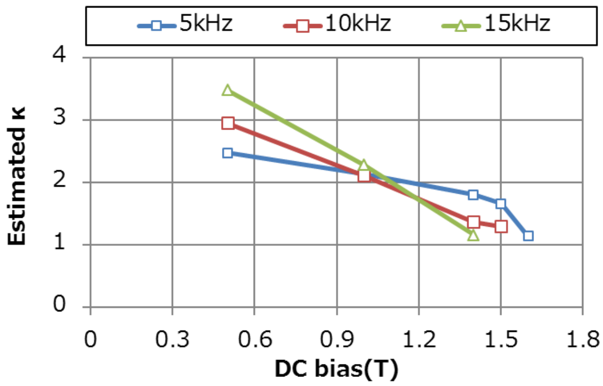


Fig. 4 Anomalous eddy current loss coefficient at direct current superposition estimated from actual measurement

2.2 Fundamental wave + harmonic Wave evaluation

Next, we verified the iron loss calculation for arbitrary waveforms including harmonics, which is the purpose of the proposed method. The harmonic components were measured and analyzed in a state where they were superimposed on the fundamental. This experiment was conducted on the assumption that a minor loop is generated by superimposing harmonic components on the fundamental wave, and that play model is required. An electromagnetic steel sheets, 35A360, processed into a ring shape by wire cutting was used. The driving condition assumed the space harmonics component of a motor, and the amplitude of 20% and the 7th harmonics component were superimposed on the fundamental wave of frequency 50-400 Hz. The harmonics are up to 2.8 kHz, which is the applicable range from the 2.1 verification. Fig. 5 shows an example of the resulting BH curve. In the analysis, the results of the conventional method and the proposed method (hysteresis loss: play model, classical eddy current loss: FEA, anomalous eddy current loss: method of this report) were used.

Fig. 6 shows the comparison result when the fundamental wave amplitude is 1.4T. The proposed method (Prop. (var.x)) accurately reproduces the measurement at all frequencies. On the other hand, in the conventional iron loss calculation method (Conventional), tends to underestimate the losses as the frequency increases. This is because the amount of direct current superposition of harmonics (the position in the major loop) is not considered in the conventional method, and the necessity of the play model is now established. Further, Prop. (const.x) shows a case where the anomalous eddy current loss coefficient is made constant at a value of 1.58 identified at 50 Hz in the play model +1 D method. In particular, the higher the frequency, the more it overestimated compared to the actual measurement. This is because the anomalous eddy current loss coefficient is too large, and it is necessary to identify the anomalous eddy current loss coefficient at each operating point.

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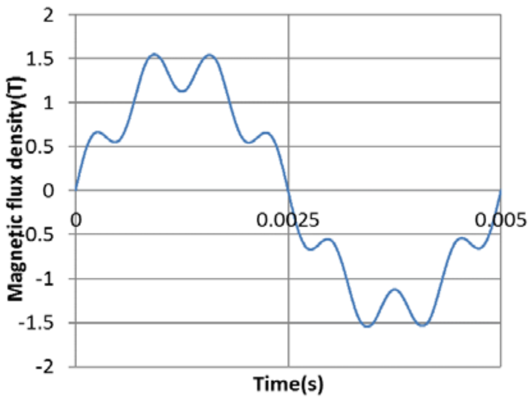
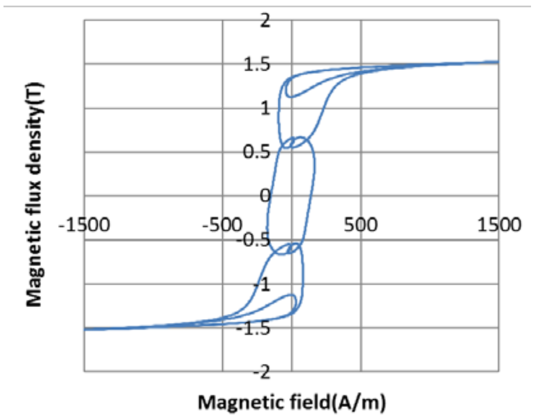


(a) Magnetic flux density waveform



(b) Hysteresis loop

Fig. 5 Example of fundamental + 7th harmonic waveform

7th harmonic component is superimposed on the fundamental (1.4 T / 200 Hz) minor at various positions in the major loop it can be seen that the loop is configured.

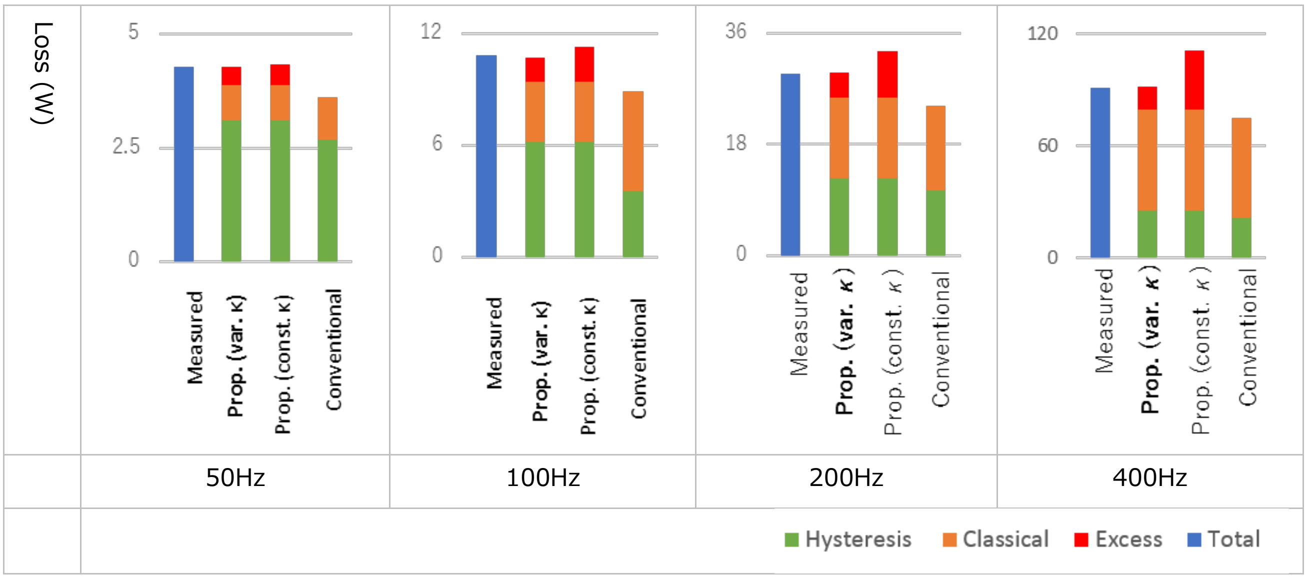


Fig. 6 Comparison of Harmonic Loss

Fundamental + 20% seventh harmonic was applied to the ring sample (35A360). Conventional eddy current loss is the sum of anomalous eddy current loss and classical eddy current loss. It can be seen that the new method reproduces the actual measurement, as compared to the conventional method which cannot reproduce the DC superimposed component and is underestimated. At 400 Hz, if the anomalous eddy current loss coefficient is constant, the loss will be overestimated.

3. Limits of the method

3.1 Dependence of coefficients

As shown in Fig. 1, the anomalous eddy current loss coefficient identified by the proposed method changes in a complex manner with magnetic flux density and frequency. A coefficient is identified temporarily to 400 Hz, and the frequency characteristic of the iron loss obtained by extrapolating smoothly on the high frequency side is shown in Fig. 7. The iron loss is underestimated because the coefficient increase after 1 kHz is not taken into consideration. Therefore, in order to apply the anomalous eddy current loss coefficient according to the proposed method, it is necessary to cover the frequency in the range to be calculated and identify the coefficient. In the future, it is necessary to confirm this property on a wide range of steel types.

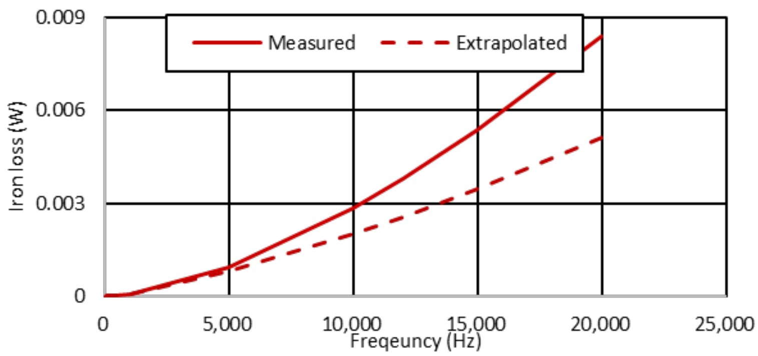


Fig. 7 when extrapolating the coefficient identified at low frequency

Iron loss value is underestimated because it does not consider the increase in coefficient after 1 kHz.

3.2 Physical modeling

In the proposed method, since the anomalous eddy current loss coefficient is identified under sinusoidal excitation conditions without DC superposition, application to the DC superposition state resulted in an error. In addition, since the frequency dependence of the coefficients cannot be described by a simple function, it is necessary to identify the coefficient by covering the whole range of used frequencies. Although the hysteresis loss and eddy current loss are obtained using a model simulating the physical phenomenon with the play model and the 1D method, the anomalous eddy current loss generated can only be obtained accurately within the limits of magnetic field flux and frequency set during the measurements. It is therefore, desirable to introduce physical modeling that covers the superimposed DC field and the whole frequency range even for anomalous eddy current loss.

4. Conclusion

- In order to improve iron loss calculation accuracy by harmonics, a modeling method of anomalous eddy current loss using the play model and 1D method were examined.
- It was confirmed that accuracy was improved compared to the conventional method with respect to the alternating current magnetic flux density waveform including harmonics if the frequency within the measurement range in the ring sample (to 1 kHz).
- However, when the frequency is 5 kHz or more, there are remaining challenges such as the behavior of the anomalous eddy current loss coefficient and the application of the coefficient to the direct current superimposed state, and those points require further study and examinations

5. References

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