Proposal of a measurement-based approach for high frequency iron loss prediction of soft magnetic materials

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The frequency range used by electrical machines is increasing due to the increasing of semiconductor switching frequency. To evaluate the efficiency of electrical machines connected to power electronics, we derive a concise iron loss calculation formula for soft magnetic materials using discrete Fourier transform theoretically and discuss in detail the characteristics of coefficients in the formula. The iron losses in high frequency range are predicted and confirmed with the measurement results.

Keywords: soft magnetic material; Fourier transform; high frequency; iron loss

1. Introduction

With the development of wide-bandgap semiconductors capable of high-speed switching, such as silicon carbide and gallium nitride devices, the switching frequency of power electronics has reached MHz [1, 2]. For accurate efficiency evaluation of electrical machines connected with power electronics supply, it is necessary to measure the high frequency magnetic properties of soft magnetic materials used as iron cores. However, magnetic measurements in high frequency range require a very large-capacity power supply, which limits the measurable frequency range.

In this research, we derive a formula for calculating iron loss in soft magnetic materials using the discrete Fourier transform theoretically. The frequency characteristics of the two crucial coefficients in the derived equation are obtained using the measured iron losses in the low frequency range. The iron losses in the high frequency range are predicted and compared with the measured results.

2. Iron loss equation

In the case of alternating excitation, flux density B is a sinusoidal waveform as shown in (1), and the magnetic field H obtained by performing a discrete Fourier transform has multiple odd harmonics according to the origin symmetry of odd functions as shown in (2).

$$B = B_{\max}\sin\omega t \tag{1}$$

$$H = H_{1\max}\cos(\omega t+\varphi_1) + H_{3\max}\cos(3\omega t+\varphi_3) + H_{5\max}\cos(5\omega t+\varphi_5) + H_{9\max}\cos(9\omega t+\varphi_9) + \ldots + H_{(2n+1)\max}\cos\left((2n+1)\omega t+\varphi_{(2n+1)}\right) \tag{2}$$

where $B_{\max}$ is the amplitude of flux density, ω is the angular frequency. $H_{i\max}$ and φ_i are the amplitude and phase angle of the i-th frequency component of H, and n is a natural number. The integration of the odd harmonics of H with B are zero, so the area of the symmetrical hysteresis loop formed by the above B and H becomes:

$$\int_0^T H\, dB = \pi B_{max} H_{1max} \cos\varphi_1 \tag{3}$$

Therefore, the iron losses are only related to the amplitude of flux density, the amplitude and phase angle of the fundamental component of H. Here, the coefficients $H_{1\max}$ and $\cos\varphi_1$ that contribute to iron loss are called the iron loss coefficients.

3. Results and discussion

From the measured values from 200Hz to 800Hz, the frequency characteristics of the iron loss coefficients are obtained and functionalized, making it possible to predict iron losses in high frequency range. Figure 1 shows comparison of the predicted and the measured iron losses up to 20kHz. The measured values are well reproduced. More details and explanations will be shown in the full paper.

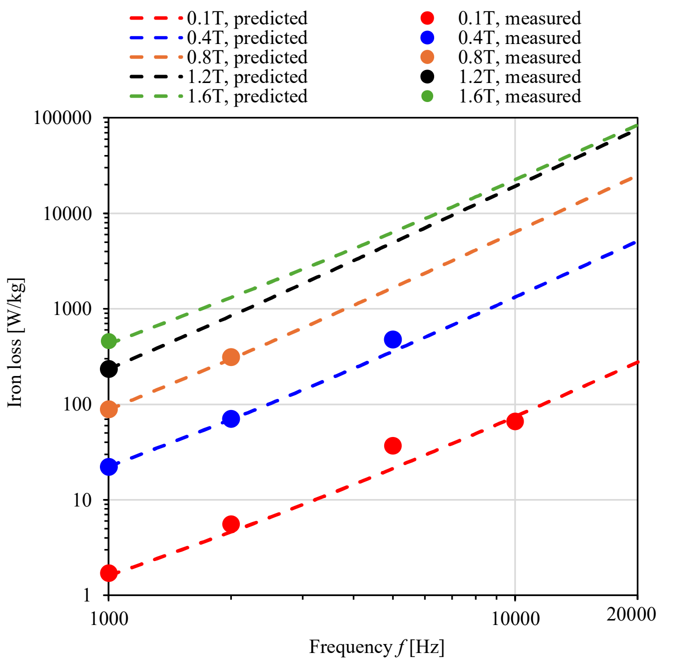

Figure 1: Comparison of the measured and predicted iron losses to 20kHz.

References

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