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Prediction of high frequency core loss for electrical steel using the data provided by manufacturer

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ABSTRACT

This paper describes a technique to determine the core loss data, at high frequencies, using the loss data provided by the lamination manufacturer. Steinmetz equation is used in this proposed method to determine core loss at high frequency. This Steinmetz equation consists of static hysteresis and eddy current loss. The presented technique considers the coefficients of Steinmetz equation as variable with frequency and peak magnetic flux density. The high frequency core loss data, predicted using this model is compared with the catalogue data given by manufacturer and very good accuracy has been obtained for a wide range of frequency.

1. Introduction

Nowadays electric motors are used in various industries as variable speed drives. Variable speed drives involve operation of motors in a wide range of speed using variable frequency power supply. A variable frequency power supply generally is voltage source or current source inverter controlled by different PWM techniques. With the use of inverter, the input voltage and current to the motor become rich in harmonics [1–5]. Besides slotting effect of stator and rotor, the supply harmonics also effects the core loss of the motor [6–10]. To determine the effect of the harmonics on the core loss of a motor, it is necessary to have core loss data for corresponding harmonic frequencies. In addition to electric motors, there are many other electric devices, where loss data of the core material is essential [11–14]. Usually, the electrical steel core manufacturers give core loss data for a limited range of frequency [15]. Authors in paper [16] proposed a new Epstein frame for lamination core loss measurement under high frequencies. Hence, there is a need to develop a method to obtain loss data at higher frequencies using catalogue data given by manufacturer.

Generally core loss consists of different types of losses. These losses have been investigated by researchers since a century [10–14,17–32]. Initially, to calculate the remagnetization losses of electrical steel, an empirical relation was proposed by Steinmetz [17] as

$$P = C_m f^{\alpha} B_m^{\beta} \tag{1}$$

In the above equation, P represents the power loss per volume (W/m^3), B_m is peak flux density (T) and f is frequency (Hz). C_m, α and β are the Steinmetz empirical parameters. Eq. (1) shows that power loss (P) depends on the coefficients C_m , α and β, where the typical range of α and β are $1 < \alpha < 3$ and $2 < \beta < 3$. With further research core loss is divided into two parts as static hysteresis loss and eddy current loss [10] and the equation is

$$P = K_h f^{\alpha} B_m^{\beta} + K_e f^2 B_m^2 \tag{2}$$

Here K_h is static hysteresis loss coefficient and K_e is eddy current loss coefficient. To increase the accuracy in core loss calculation an excess loss component, accounting for dynamic loss was added [18] and the new core loss equation was given

$$P = K_h f B_m^{\beta} + K_e f^2 B_m^2 + K_a f^{1.5} B_m^{1.5} \tag{3}$$

Other methods to predict the core loss that are not based on Steinmetz equation are also presented in the literature [20–28]. However, these methods are mathematically complex for design and analysis of electrical machines [29]. Hence, Steinmetz's equations are mostly used in core loss calculation.

Authors in [30] have used modified form of (2), with coefficients K_h, β and K_e to predict the core loss considering value of α as 1. In this work, K_h was considered to be a function of frequency, whereas, β and K_e were considered to be functions of both frequency and peak flux density. In another work from the same

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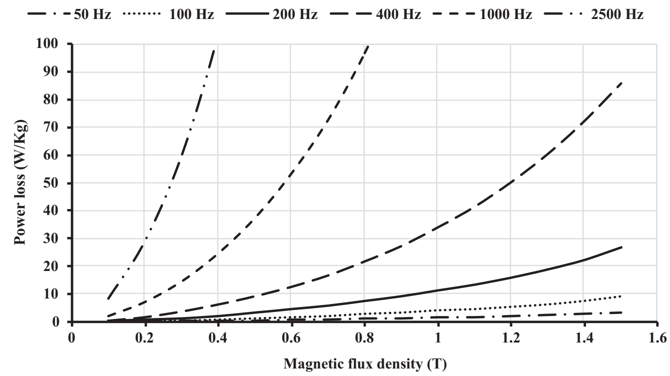

Fig. 1. Variation of core loss with flux density at different frequencies for M350-50A.

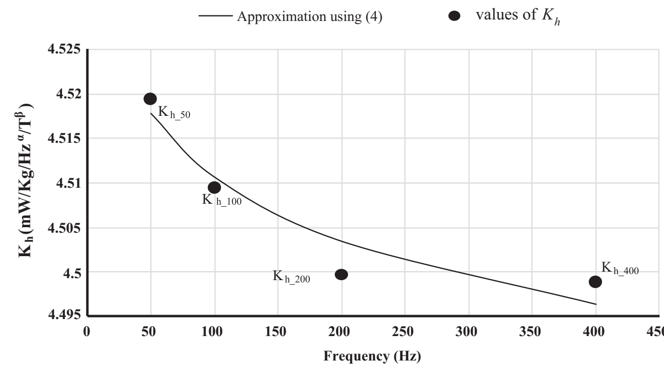

Fig. 2. K_h values at different frequencies and its approximation with (4) for M350-50A.

authors [31], both K_h and K_e were taken to be functions of frequency and peak flux density, while constant values were assigned for α and β as 1 and 2 respectively. In [32], iron loss was predicted for high frequency using low frequency loss data. Here, authors have used (3) and have considered all the coefficients (K_h, K_e, K_a and β) to be function of only peak flux density. However, the losses predicted at higher frequencies have significant error with respect to experimental values especially for lower value of magnetic flux density. The proposed technique also needs core loss data for large number of frequencies as input. Generally, the electrical steel manufacturers give loss data for limited number of frequencies. Thus, it has been observed that, there is significant scope for improvement in the methods to predict high frequency loss data from the data supplied by the electric steel manufacturers.

The objective of the presented work is to propose a technique to predict high frequency loss data using the data given by manufacturers. The technique developed in this work uses the Steinmetz's Eq. (2) to predict the core loss data at high frequencies. All the coefficients in this equation are considered to be functions of frequency and peak flux density. To validate the proposed technique, nine different materials have been considered.

The next section presents the proposed technique in detail. Different steps of the complete procedure are given in Section 3. The analysis of the results is described in Section 4. In Section 5 conclusions are drawn.

2. Overview of the method

To explain the method in detail, material M350-50A is chosen. The typical core loss data for this material given by the manufacturer is shown in Fig. 1 [15].

For this material, four frequencies are considered, namely 50 Hz (f_{50}), 100 Hz (f_{100}), 200 Hz (f_{200}) and 400 Hz (f_{400}). The numerical values of core loss at these frequencies are given in Table 1. Only a small set of data is shown in Table 1.

Initially, curve fitting is done on the given power loss vs. induction values mentioned in Table 1 in descending order of the frequency. For the considered example, the curve fitting starts with the core loss data at 400 Hz and the curve fitting is done subsequently for the loss data of 200 Hz, 100 Hz and 50 Hz. Using the curve fitting, the coefficients (K_h, K_e, α and β) given in (2) are determined for all the four frequencies. Since, the numbers of coefficients are four, a minimum of four data points are needed for curve fitting at each frequency. Applying this procedure for all frequencies, a set of values for K_h, K_e, α and β are obtained and are given in Table 2.

From Table 2 it can be observed that for material M350-50A the coefficients are functions of frequency. Flux density presented in Table 1, is the average cross-sectional value (and also the maximum value in time). Since this type of material has a high value of relative magnetic permeability, so there is a phenomenon of uneven flux distribution inside the material, which causes the

Table 1
Flux density vs. power loss data for M350-50A.

k	B (T) [B_k]	W/kg (50 Hz) f_{50}	W/kg (100 Hz) f_{100}	W/kg (200 Hz) f_{200}	W/kg (400 Hz) f_{400}
1	0.1	0.02	0.06	0.17	0.48
2	0.2	0.09	0.24	0.62	1.75
3	0.3	0.18	0.5	1.3	3.62
4	0.4	0.3	0.81	2.15	6.02

Table 2
Value of coefficients at different frequencies for M350-50A for the values given in Table 1.

f	Value of coefficients			
	K_h (10^{-5} W/kg/Hz$^\alpha$/T$^\beta$)	K_e (10^{-5} W/kg/Hz^2/T^2)	α	B
f_{50}	0.0451 (K_{h_50})	3.7624 (K_{e_50})	1.3064 (α_{50})	1.7219 (β_{50})
f_{100}	0.0450 (K_{h_100})	3.7400 (K_{e_100})	1.3035 (α_{100})	1.7135 (β_{100})
f_{200}	0.0449 (K_{h_200})	3.7177 (K_{e_200})	1.3007 (α_{200})	1.7067 (β_{200})
f_{400}	0.0449 (K_{h_400})	3.7029 (K_{e_400})	1.3004 (α_{400})	1.7000 (β_{400})