

Applicability of Different Dynamic Magnetization Models for Non-oriented Steel in Rolling and Transverse Directions

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In this research, we applied different analytical and numerical dynamic magnetization models on Non-oriented (NO) steel to reproduce the magnetization field $H(B)$ and energy loss in both Rolling and Transverse Directions. The conventional analytical dynamic magnetization model applied is the well-known Bertotti's three-term model, in which a simplified equation for the classical eddy current loss is used. And the numerical model applied is the one-dimensional (1D) finite element model, which is a nonlinear eddy current analysis with modified conductivity, hence nonlinearity, skin effect, and excess loss are all included. Both models can provide a reliable basis for energy loss through choosing parameters fitting with the measured loss. But use of the Bertotti's model provides too much straight dynamic loop shapes compared with the measured ones, vice versa for the use of the 1D model. Therefore, the combination method of the two models is proposed. It shows the best performance among the three to represent the dynamic loop shape, and hence energy loss for both the NO steel in rolling and transverse directions.

Index Terms—Dynamic magnetization model, Finite element method, NO steel, rolling direction, transverse direction.

I. INTRODUCTION

ACCURATE CALCULATION of the energy loss of non-oriented (NO) steels is a well-discussed topic. There are many existing methods for prediction of energy loss, analytically or numerically. The typical analytical method is the well-known Bertotti's three-term model, in which a simplified equation is used for the classical eddy current loss [1]. The typical numerical method is the one-dimensional (1D) finite element model, which is a nonlinear eddy current analysis with modified conductivity, hence nonlinearity, skin effect, and excess loss are all included [2]. These methods all provide a good prediction of energy loss [2], [3], [4]. However, they lack representation of the dynamic loop shape, especially high frequencies with low amplitude.

As a matter of fact, energy loss is a result of the dynamic loop, so the loop shape should come first. Therefore, in this research, we evaluate the representation ability of the dynamic loop shape, and hence energy loss of different analytical and numerical dynamic magnetization models on a NO steel in rolling direction (RD) and transverse direction (TD) under a wide range of different frequencies and amplitudes and compare with the measured results.

II. DYNAMIC MAGNETIZATION MODELS

A. Bertotti's model

The Bertotti's three-term model with the DC magnetization field H_{DC} , the classic field H_{cl} , and the excess field H_{exc} , is shown as follows.

$$H_{AC}(t, B) = H_{DC}(t, B) + H_{cl}(t, B) + H_{exc}(t, B) \\ = H_{DC}(t, B) + \frac{\sigma a^2}{12} \frac{dB}{dt} + \sqrt{\sigma S G V_0} \delta \left| \frac{dB}{dt} \right|^{0.5} \quad (1)$$

where S is the cross-sectional area of the silicon steel, G is 0.1356, which is a dimensionless coefficient, and directional parameter δ is $\delta = +1$ for $dB/dt > 0$, and $\delta = -1$ for $dB/dt < 0$. V_0 is a statistical parameter, which depends on the peak of flux

density and frequency, it is determined by fitting the calculated coercivity with the measured one. Fitting with coercivity is chosen because it is not affected by the shape of the measured material [5]. The magnetization of DC hysteresis loop is separated from hysteresis loop of 50Hz using a direct iteration calculation method [6]. By using (1), the magnetization field $H(B)$ can be calculated and B - H loops can be obtained.

B. 1D model

The 1D finite element model of the NO steel is half of one sheet both for rolling and transverse directions. A uniform alternating excitation B_{0y} with different amplitudes and frequencies are applied along the plane direction by using the Dirichlet boundary conditions.

The DC hysteresis and excess characteristics are considered in the 1D model as follows by introducing a reaction magnetization field and a correction factor into the general eddy current analysis.

$$rot(v_{initial} rot A) = rot H_{reaction, DC} - K_a \sigma \frac{\partial A}{\partial t} \quad (2)$$

where $H_{reaction, DC}$ is the difference of magnetization field between the initial B - H curve and the DC hysteresis loop as shown in Fig. 1. The correction factor K_a for the excess loss is dependent on $B_{0y, max}$ and frequency. It is determined by equalizing the calculated coercivity with the measured one.

C. Combination of Bertotti's model and 1D model

The combining method of the Bertotti's model and the 1D model, in which H_{DC} and H_{cl} are from (2) with K_a equal to 1 and H_{exc} from the Bertotti's model of (1), is also investigated.

RESULTS AND DISCUSSIONS

The dynamic hysteresis loops of the NO steel are measured using the Epstein tester following the JIS standard with amplitude up to 1.7 T and frequency up to 1000 Hz. The samples are cut in the rolling direction and perpendicular direction, respectively and analyzed correspondingly. Fig. 2 shows the comparison of calculated dynamic loops of the NO

steel in the rolling and transverse directions with measured ones at 1 T and 400 Hz. Fig. 3 shows the relative error of the calculated iron losses using different models.

A close examination of Fig. 2 reveals that discrepancies exist between the predicted loop of Bertotti's model and the measured one, particularly at the ascending part. The 1D method and the combination method provide better accuracy of loop shape at the ascending part.

According to Fig. 3, Bertotti's model provides a fairly good accuracy (error within 5%) for energy losses at low frequencies for both rolling and transverse directions, but fails at high frequencies. The 1D method and the combination method provide a fairly good accuracy (error within 5%) for energy losses at all frequencies for rolling, but lack of accuracy for the transverse direction at high frequencies.

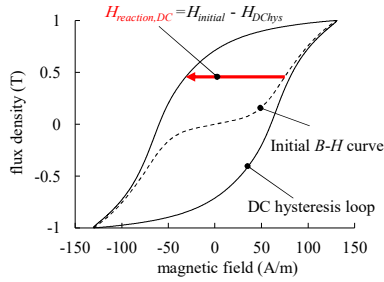


Fig. 1. Reaction magnetization field due to DC hysteresis.

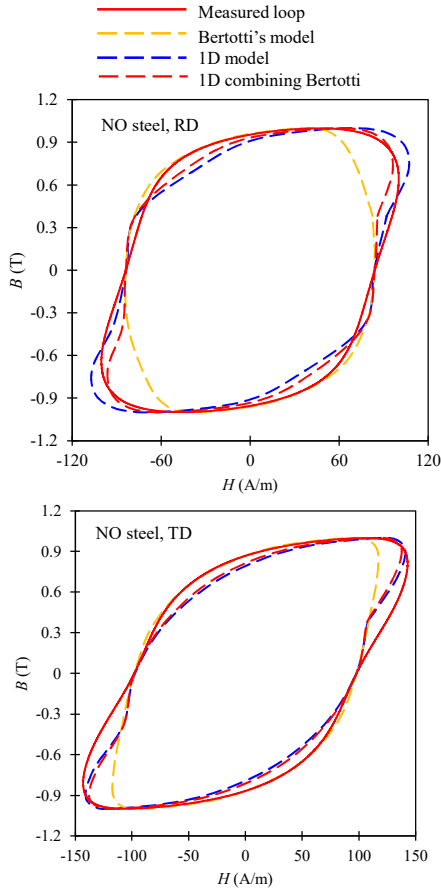


Fig. 2. Comparison of calculated dynamic loops of NO steel in Rolling and Transverse directions with measured ones, 1T and 400Hz.

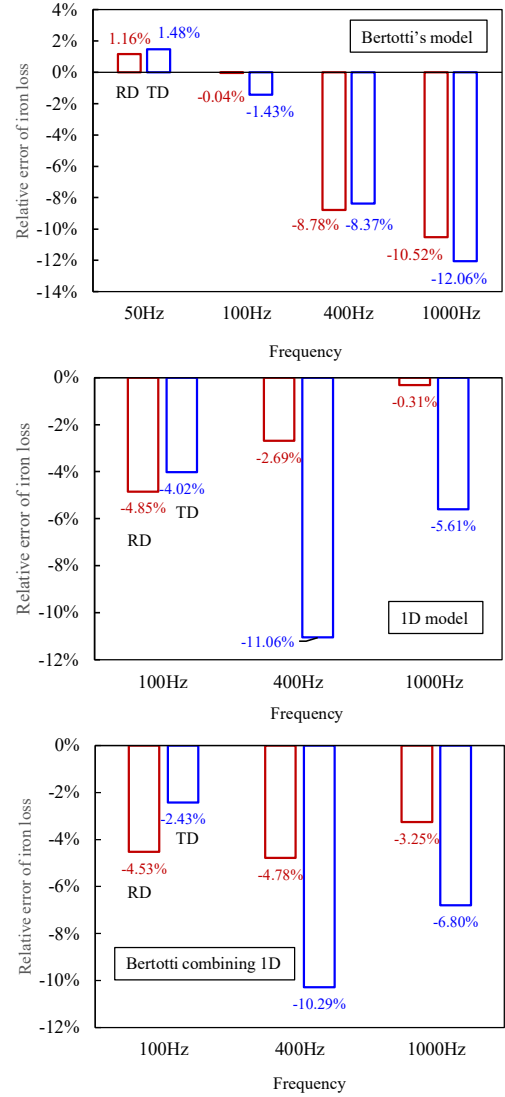


Fig. 3. Relative error of calculated iron losses of NO steel in Rolling and Transverse directions, 1T.

More investigation using other dynamic magnetization models and results will be given in the full paper.

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