

Loss separation in NO electrical steels

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It is important for metallurgists working on electrical steels and engineers involved in the loss prediction to subdivide the total loss, W_{tot} , into components called hysteresis loss, W_{h} , classical eddy current loss, W_{clas} , and excess loss, W_{exc} . In the case of magnetic induction with peak value B_p , varying sinusoidally at frequency f , the value of W_{clas} is almost exclusively calculated by the formula [1]

$$W_{\text{clas}} = \frac{d^2 \pi^2 B_p^2}{6\rho} f \quad (1)$$

where d is the thickness of the lamination, and ρ is the electrical resistivity.

It is usually neglected that equation (1) results from the theory developed for a magnetically linear medium magnetized at low frequency. Neither of these conditions is met in reality, so the use of this theory can lead to doubtful quantitative estimates of the classical loss and, especially excess loss, found by conventional subtracting technique:

$$W_{\text{exc}} = W_{\text{tot}} - W_{\text{clas}} - W_{\text{h}}. \quad (2)$$

The purpose of our work is to evaluate and explain corresponding errors. In this study attention is confined to nonoriented (NO) electrical steel. It focuses mainly on the classical loss due to its dominant contribution to the whole dynamic loss (W_{clas} plus W_{exc}) that can lead to large relative errors in W_{exc} even at moderate errors in W_{clas} . The choice of NO steel is also made because its domains are much smaller than the sheet thickness. This allows the processes in NO laminations to be described by the magnetodynamic models (MDM) [2], [3] which are solvers of classical Maxwell equations combined with dynamic hysteresis models. In this paper the MDM [2] is applied to NO steel ($\rho=0.43 \mu\Omega\cdot\text{m}$, $d=0.5 \text{ mm}$) for which its error in the total loss prediction is within 2% of measured values in the frequency range of 50 to 600 Hz. This fact along with the ability of the model to reproduce the shapes of dynamic hysteresis loops under sinusoidal and nonsinusoidal flux densities makes the MDM a reliable source of reference data for total loss and its three components.

Using this data, the relative errors using equation (1) at $f=50 \text{ Hz}$ and $B_p=0.5, 1.0$ and 1.5 T were found to be +24%, +4% and -9%, respectively. When using the subtracting technique, this leads to the errors in W_{exc} equal to -36%, -7%, and +26%. At $f=100 \text{ Hz}$, the errors in W_{exc} increase to -74%, -18%, and +53%. The signs and the values of these errors are explained in the paper by studying the flux distribution inside the lamination and making reference to the saturation wave theory [4].

These large errors show that (1), like any other simple equation of this type, is not a reliable basis for evaluating excess loss through (2). The use of numerical models like those in [2] or [3] is necessary for the loss separation. This does not mean, however, that equation (1) cannot be used in loss predictions but it should be viewed as an approximate conditional expression.

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