Improved Numerical Calculation of Excess Loss in Magnetic Sheet Considering Domain Wall Bowing

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In this paper, the numerical calculation of iron loss in silicon steel plates considering the domain wall bowing is carried out. The domain wall bowing, which contributes to the excess loss, is considered by applying an initial flux distribution along the sheet thickness into a nonlinear eddy current finite element analysis. The initial flux distribution is assumed to take the shape of parabola with different wall bowing degrees and average values. The iron loss including the excess loss can be calculated using the obtained flux and eddy current density directly. In the range of 100 Hz ~ 1000 Hz, the calculated iron losses are compared with the measured data in the catalogue, 5% maximum deviation is achieved.

***Index Terms*—Excess losses, magnetic materials, numerical analysis, silicon steel sheet.**

I. Introduction

To separate and predict the iron loss for design of green electric machines, evaluation of excess loss is important. The authors had proposed a numerical calculation method of excess loss in a grain-oriented silicon steel sheet [1]. In this method, the domain wall bowing, which contributes to the excess loss [2], [3], [4], was taken into account by applying an initial flux distribution along the sheet thickness into a nonlinear eddy current finite element analysis (FEA). The domain wall bowing degree (DWBD) was defined and the excess loss was correlated with DWBD using an exponential equation. The calculated excess loss using the proposed equation was compared with that in the catalogue. Using the equation, the excess loss can be predicted under harmonic frequency in the range of 50 Hz ~ 2000 Hz, whereas it is not applicable to non-oriented materials.

In this paper, the numerical calculation method of excess loss considering the domain wall bowing is investigated further and improved to suitable for both grain-oriented and non-oriented materials. First, the method considering the domain wall bowing by applying an initial flux distribution is investigated further with different wall bowing degrees and average values. Second, the excess loss is calculated using the eddy current density obtained from the proposed eddy current FEA directly instead of the exponential equation. The improved method is applied to a non-oriented silicon steel sheet first and the results are reported. The obtained iron losses with wall bowing degree 0.3 and average flux density zero shows 5% error the maximum in the range of 50 Hz~1000 Hz compared with the measured data in the catalogue.

I. Numerical Model Considering Domain Wall Bowing

A. Analysis model and conditions

The analysis model is half of a steel plate in its thickness cross-section as shown in Fig. 1. The thickness d of the non-oriented steel plate is 0.35 mm. Sinusoidal magnetic field with amplitude of B_{max} 1 T (frequency f: 50 Hz ~ 1000 Hz) is imposed through the Dirichlet boundary condition. The initial B-H curve of the material is used considering its nonlinearity. The model is meshed taking into account of the skin depth thus the skin effect is considered. The domain wall bowing degree DWBD is defined as $(B_s-B_{ave})/B_s$, where B_s is the surface degree of flux density in the sheet, and B_{ave} is the average degree of flux density across the sheet thickness.

B. Eddy current finite element analysis

To take into account the wall bowing, the 1-D nonlinear eddy current FEA is performed introducing an initial flux distribution $\boldsymbol{B}_p$ along the sheet thickness assumed to represent the bowing generated by the pinning effect. The fundamental equation of the 1-D nonlinear eddy current FEA is

$$-\frac{\partial}{\partial z}\left(\nu\left(\frac{\partial \boldsymbol{A}}{\partial z}-\boldsymbol{B}_p\right)\right)+\sigma\frac{\partial \boldsymbol{A}}{\partial t}=0 \qquad (1)$$

where ν is the reluctivity and σ is the conductivity of the magnetic material. $\boldsymbol{B}_p$ is assumed to take the shape of parabola [3], which follows the function of $\boldsymbol{B}_p^{(ie)} = az^2+b$, where a, b are constants, $\boldsymbol{B}_p^{(ie)}$ is the flux density of each element ie and z is the coordinate of element center in the thickness direction. The applied values of $\boldsymbol{B}_p^{(ie)}$ with DWBD varying from 0.1 to 0.5 are shown in Fig. 2. The average flux density B_{ave} of them is 1. The same distribution with $B_{ave} = 0$ is also applied.

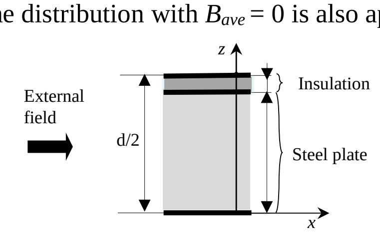

Fig. 1. Analysis 1D model: half of one steel plate.

C. Iron Loss Calculation

In real materials, both bowing due to pinning and eddy current field are expected to coexist and a complicated situation is realized, where bowing due to pinning affects eddy current field and eddy current loss, and dynamic bowing affects wall pining. By using the analysis above, the mutual coherence of bowing due to pinning and eddy current field is achieved. Thus the iron loss is calculated using the flux and eddy current density obtained from the analysis above directly. The iron loss model with two terms: the hysteresis loss W_h and the eddy current loss W_e used is as follows [5], [6], [7].

$$W_i = W_h + W_e = \left[\sum_{i=1}^{Ne} \left\{ K_{h,B_{max}}^{(i)} f + \left(\sum_{j=1}^{Ns} \frac{Je^{(i,j)2}}{\sigma} \right) \Big/ Ns \right\} l^{(i)} \right] \Big/ \sum_{i=1}^{Ne} l^{(i)} \quad (2)$$

where Ne is the total element number, $K_{h,Bmax}$ is the hysteresis coefficients varying with the amplitude of the flux density B_{max} in each element, which is obtained by using the iron-loss characteristics of the steel plate with f of 50 Hz and 60 Hz in the catalogue data, Ns is the total time step, Je is the eddy current density, and l is the length of each element. And this method takes the advantage of no parameters determination in comparison of the exponential equation in [1].

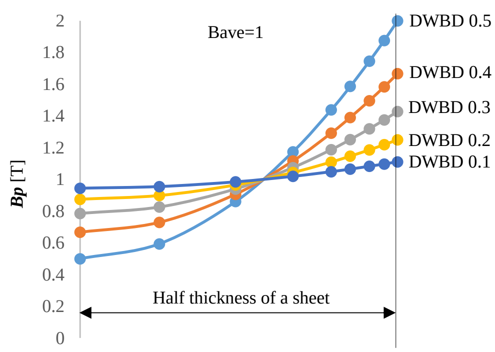

Fig. 2. The applied values of the initial flux distribution $\boldsymbol{B}_p$ in the thickness direction.

II. Results and Discussion

A. Bave=1

The calculated iron losses versus frequency when B_{ave} = 1 are shown in Fig. 3 and compared with measured data W_m in the catalogue, and there are only calculated results with DWBD of 0.2 and 0.3 for they match the measured data. The calculated iron losses obtained without $\boldsymbol{B}_p$ is also shown. One can observe that the calculated iron loss increases with the wall bowing compared with that without. And the calculated iron losses with the wall bowing approach the measured one with increasing DWBD. The maximum deviation of the calculation with DWBD 0.3 and the measurement is about 10% the in the range of 50 Hz ~ 1000 Hz.

B. Bave=0

The calculated iron losses versus frequency when B_{ave} = 0 are shown in Fig. 4 and compared with measured data. With DWBD 0.3, the calculated results show good agreement with the measured data, with maximum deviation of 5% in the range of 50 Hz ~ 1000 Hz.

III. Conclusion

The numerical calculation of excess loss in a non-oriented steel sheet taking into account the domain wall bowing by using a nonlinear eddy current analysis applying an initial flux distribution along the sheet thickness is carried out. The obtained iron losses using the proposed method show good agreement with the measured data in the catalogue. Application of the improved method on grain-oriented materials and comparison with experiment will be demonstrated in the future.

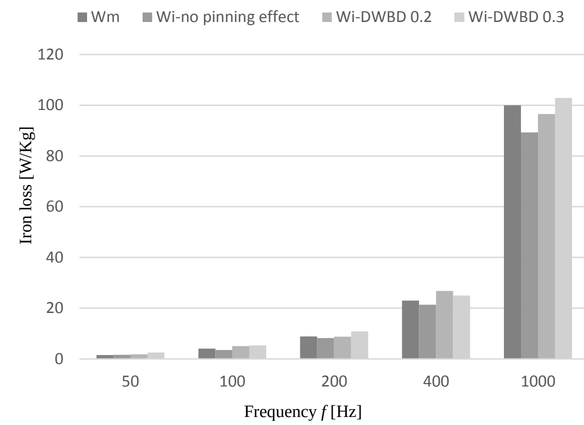

Fig. 3. The calculated and measured iron losses versus frequency.

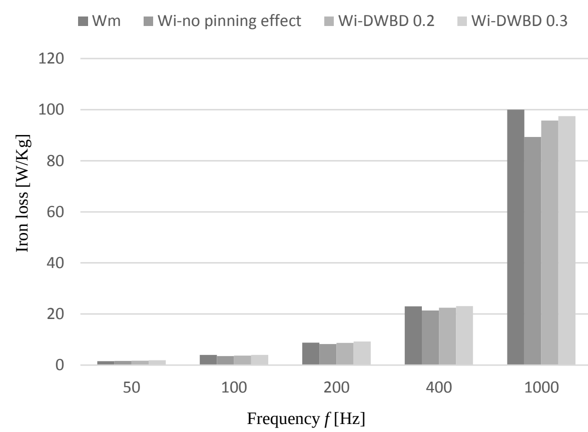

Fig. 4. The calculated and measured iron losses versus frequency.

IV. References

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