Prediction of loss increase in silicon steel sheet due to compressive stress of 100 MPa

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The loss increase in the silicon steel sheet due to the compressive stress is analyzed using a physical magnetization model, where a two-step energy minimization procedure is introduced to reduce computation time when the stress and the magnetic flux density are large. Simulated stress-dependent magnetization properties agree with measured ones with reasonable accuracy without parameter fitting to data measured under mechanical stress.

Keywords: Energy minimization, hysteresis loss, magnetization analysis, mechanical stress

1. Introduction

The mechanical stress often increases the iron loss of silicon steel sheets and hence reduces the motor efficiency. To understand the magneto-mechanical interaction, several physical magnetization models [1, 2] have been developed, which successfully predicted the stress-dependent properties. However, it is still an open problem to predict the stress dependence of hysteresis loss accurately.

The multi-domain particle model (MDPM) [2] is one of the physical magnetization models, which succeeded in predicting the increase in the hysteresis loss of silicon steel sheet due to the compressive stress without using measured data under the compressive stress of 40 MPa. The MDPM is an energy-based model, where the magnetization state is determined by minimizing the total magnetic energy. However, it sometimes requires a long computation time for energy minimization when the stress or the magnetic flux density is large.

To reduce the computation cost, a two-step energy minimization procedure was developed for the MDPM [3]. This article applies the two-step procedure to the magnetization analysis of silicon steel sheets under a large compressive stress.

2. Two-step magnetization model

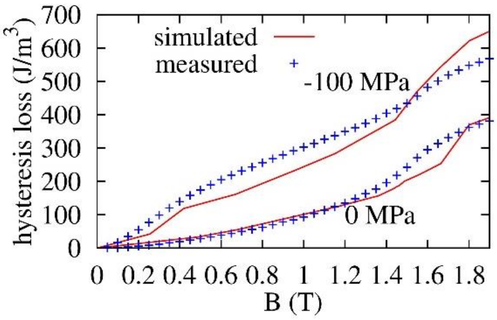
The MDPM [2] is a physical macroscopic magnetization model developed by assembling mesoscopic particles at the crystal-grain scale. The mesoscopic particle called the simplified domain structure model has six domains corresponding to the cubic anisotropy. The magnetization state in each particle is represented by the volume ratios r_i and magnetization directions (θ_i, φ_i) of the six domains (i = 1, …, 6). These variables are determined to locally minimize the total magnetic energy, which comprises the Zeeman, crystalline anisotropy, magnetostatic, and magnetoelastic energies.

The two-step energy minimization is carried out as follows. First, only the volume ratios r_i are optimized with fixed magnetization directions. Second, the volume ratios and the magnetization directions only of active domains are optimized.

3. Computational result

A non-oriented silicon steel sheet JIS: 350A300 is measured along the rolling direction with and without the compressive stress of 100 MPa. The pinning field is represented by the play model. There is a free parameter to control the magnitude of the pinning field, which is determined to adjust the simulated hysteresis loss to the measured loss under the stress-free condition. The material constants used for the computation are the cubic anisotropy constant of K = 3.66 × 10^4 J/m^3, magnetostriction constants of λ_{100} = 2.31 × 10^{-5}, λ_{111} = −4.3 × 10^{-6}, and $\mu_0 M_S$ = 2.01 T, where no measured data under the mechanical stress are required for the MDPM.

Fig. 1 compares the measured and simulated losses and BH loops, where a reasonable accuracy is obtained even with no parameter fitting to the stress-dependent data. The simulated BH curves are not very smooth because the number of mesoscopic particles used for the MDPM is small.



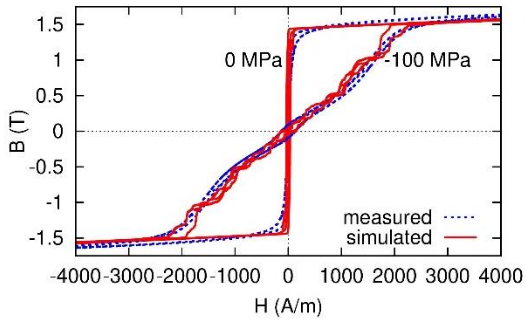


Figure 1: Measured and simulated magnetic properties with and without compressive stress of 100 MPa: (a) hysteresis losses per cycle and (b) BH loops.

References

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