

Measurement and Modeling of Anisotropic Magnetostriction Characteristic of Grain-Oriented Silicon Steel Sheet under DC Bias

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Abstract—The power transformer core is composed of grain-oriented electrical silicon steel sheets, whose magnetostrictive properties arise obvious vibration and noise of the transformer core, especially when operating under direct current (DC) bias. In this paper, the anisotropic magnetostriction characteristics of grain-oriented silicon steel sheets in the rolling direction and other directions are measured under externally applied stress and alternating magnetic field plus DC bias. The anisotropic magnetostriction model is proposed and the measured magnetostriction under DC bias and their strong dependence on the applied mechanical stress are taken into account the magnetostriction model and used to determine its coefficients. The validation of proposed model is verified with experimental results.

Index Terms—Transformer cores, Magnetostriction, Vibration, Grain-oriented steel

I. INTRODUCTION

The magnetostriction itself is the phenomenon by which a ferromagnetic sample deforms due to magnetic interactions caused as a consequence of an external magnetic field and is called Joule and dipolar magnetostriction, which is anisotropic. Magnetostriction of electrical steel sheet composing the core of transformers or rotating electrical machines makes the core vibrating periodically with the change of the magnetic field and emits noise. Recently, the modeling technique of the magnetostriction for soft magnetic materials have been proposed and coupled into magnetic finite element analysis to calculate magnetostrictive forces, displacement, and vibration modes of transformer and electrical machines [1-4]. Ref. [5-6] published in 2012 proposed a 2-D magnetostriction measurement system of non-oriented electrical steel sheet and measured magnetostriction characteristics under rotating flux conditions.

Any model of magnetostriction requires magnetostriction measurement data for the electrical steel sheet. However, owing to the difficulty of self-developed measurement system, some magnetostriction property researches, such as anisotropic characteristics at other directions besides rolling direction (RD) and transverse direction (TD) of samples, and magnetostriction under DC bias have not attracted enough attention.

In this paper, the measurement of anisotropic magnetostriction characteristics of silicon steel sheet under alternating flux condition plus direct current bias (DC bias) at

any direction of sample was carried out. By cutting the sample with special angles, the applied magnetic field direction can be controlled along the rolling direction or deviating from it. On the other hand, the change in magnetization due to applied mechanical stress has been measured and modeled by many researchers, but for electrical steel, this behavior is quite complicated since it behaves in different ways at different levels of magnetization. Inversely, the magnetostriction of electrical steel is not only field dependent but also stress dependent. Thus, in this paper, the effect of an externally applied stress on the magnetostriction hysteresis loop of electrical steel was also measured. Finally, the model of magnetostriction with stress dependence was proposed.

II. MEASUREMENT OF ANISOTROPIC MAGNETOSTRICTION CHARACTERISTICS

A. Measurement method

The measurement of magnetostriction is the foundation not only in simulation but also for the determination of coefficients in anisotropic magnetostriction model. The measurement of magnetostriction in Fig.1 was conducted using a single sheet specimen specified in IEC/TR 62581 of 500 mm long and 100 mm wide of electrical steel by means

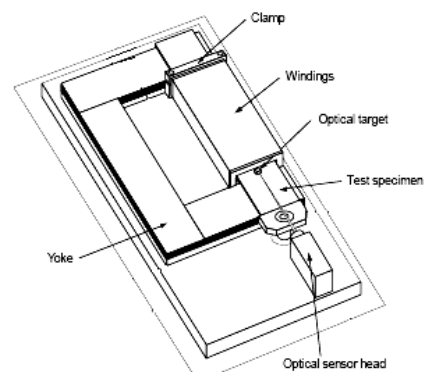


Fig. 1 Measurement systems for magnetostriction

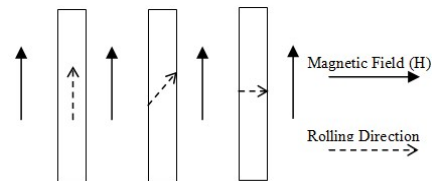


Fig. 2 Samples with different cutting directions

of optical sensors and accelerometers. Fig.2 shows electrical steel sheet 27PHD090 samples are cut by different direction from 0 degree to 90 degree by steps of 15 degree deviating from the RD so that the externally applied magnetic field is not parallel to the RD of the samples any more.

B. Measurement results

Fig.3 shows magnetostrictive hysteresis loops of a high permeability grain-oriented electrical steel 27PHD090 for peak magnetic polarization of 0.7T, 1.0T, 1.3T, 1.6T and 1.7T under alternating magnetization of 50Hz at the rolling direction, 45 degree direction with regards to rolling direction and transverse direction. From Fig.3 (a), we can see that the loops are symmetrical about y axis and through origin. As the peak magnetic polarization increases up to 1.6T, the butterfly loops begin to exhibit some reversible characteristics at the end of the loops. The reversible component gradually increases until getting stable when the peak magnetic polarization reaches to 1.7T. In Fig. 3(b), the magnetostriction almost attains to 18000 nm/m in the transverse direction and the strain is much bigger than that in the rolling direction. The results show that the magnetostriction characteristics along different directions of the electrical steel are anisotropic.

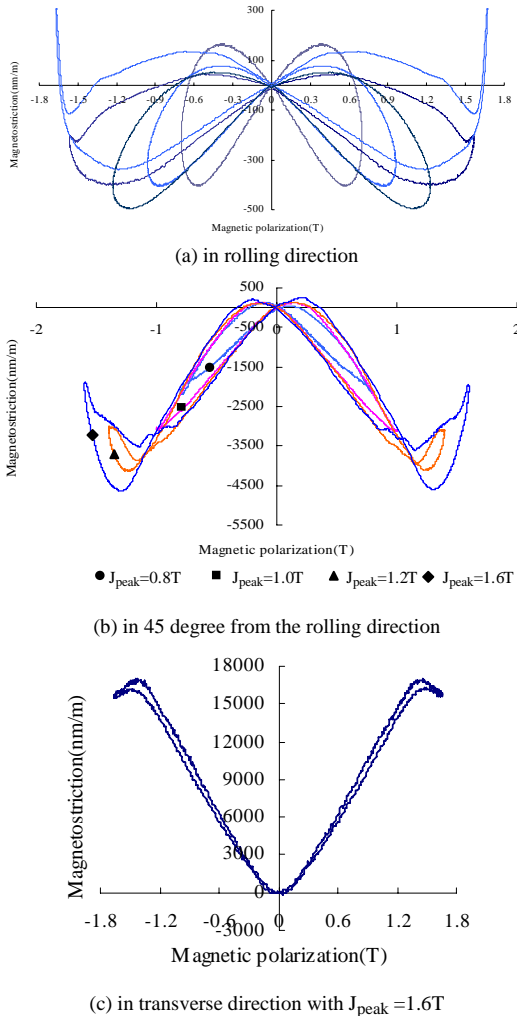


Fig.3 Magnetostrictive hysteresis loops at different directions of 27PHD090

samples

A series of magnetostrictive hysteresis loops as a function of magnetic field density under different DC bias field is shown in Fig. 4. The mechanical stress was varied as in the measurement from -6MPa to 6MPa by steps of 0.5MPa. The measurement results will be given in the extended paper.

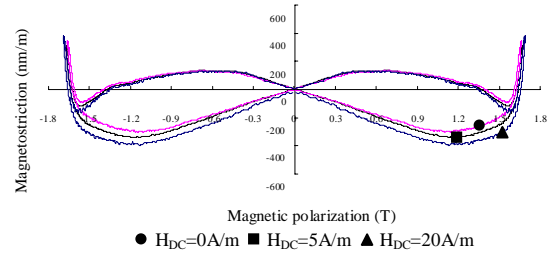


Fig.4 Magnetostrictive hysteresis loops of 27PHD090 samples with 1.7T magnetic polarization peak value under different DC bias in rolling direction

III. MODELING OF ANISOTROPIC MAGNETOSTRICTION CHARACTERISTICS

The models for magnetostriction can be separated into two main frames: elongation-base and force-based. In this paper, the elongation-base models is expressed as follows,

$$\begin{bmatrix} \varepsilon_{RD} \\ \varepsilon_{TD} \end{bmatrix} = \begin{bmatrix} E_1 \\ E_2 \end{bmatrix} \begin{bmatrix} \sigma_{RD} \\ \sigma_{TD} \end{bmatrix} + \begin{bmatrix} d_1 \\ d_2 \end{bmatrix} \begin{bmatrix} H_{RD} \\ H_{TD} \end{bmatrix} \quad (1)$$

where subscript *RD* and *TD* stands for the rolling direction and transverse direction, respectively, ε is the magnetostriction of electrical steel sample under externally applied mechanical stress σ and alternating field H . The coefficients of Young 's modulus E and piezomagnetic coefficients d in (1) are interpolation from the measured data under DC bias. The calculation of the coefficients and the verification of the model in (1) will be discussed in the extended paper.

REFERENCES

- [1] T. Hilgert, L. Vandeveld, J. Melkebeek, "Comparison of magnetostriction models for use in calculations of vibrations in magnetic cores," *IEEE Trans. Magn.*, vol. 44, no. 6, pp. 874-877, 2008.
- [2] B. Weiser, H. Pfützner, J. Anger, "Relevance of magnetostriction and forces for the generation of audible noise of transformer cores," *IEEE Trans. Magn.*, vol. 36, no.5, pp. 3759-3777, 2000.
- [3] P. S. Shin, H. J. Cheung, "A magnetostrictive force and vibration mode analysis of 3 kW BLDC motor by a magneto-mechanical coupling Formulation," *Journal of Electrical Engineering & Technology*, vol. 6, no. 1, pp. 76-80, 2011.
- [4] O. Mohammed, T. Calvert, R. McConnell, "Coupled Magnetoelastic finite element formulation including anisotropic reluctivity tensor and magnetostriction effects for machinery applications," *IEEE Trans. Magn.*, vol. 37, no. 5, pp.3388-3392, 2001.
- [5] S. Somkun, A. J. Moses, P. I. Anderson, "Measurement and modeling of 2-D magnetostriction of nonoriented electrical steel," *IEEE Trans. Magn.*, vol. 48, no.2, pp. 711-714, 2012.
- [6] S. Somkun, A. J. Moses, P. I. Anderson, P. Klimczyk, "Magnetostriction anisotropy and rotational magnetostriction of nonoriented electrical steel," *IEEE Trans. Magn.*, vol. 46, no. 2, pp. 302-305, 2010.