Effect of Variation of DC Bias on Loss and Flux inside GO Electrical Steel Lamination

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Abstract—**This paper proposes a new measurement method for the magnetic properties of GO (Grain Oriented) electrical steel under dc-biased working condition, having the advantage of no interplay between ac and dc excitations; hence, making the control easy as compared with the usual technique. The modeling of such magnetic properties is presented, based on a laminated core model (LCM), at the product level, and the effects of variation of dc-biased magnetic field intensity on iron loss and flux are examined.**

Index Terms—**DC bias, GO electrical steel, magnetic property.**

I. INTRODUCTION

The dc bias of power transformer occurs frequently due to the HVDC's monopole operation mode with ground return. An iron core under dc-biased magnetization generates a distorted and asymmetrical hysteresis loop, resulting in a higher iron loss compared with that under sinusoidal excitation [1], [2].

Although the accurate measurement of magnetic properties under dc-biased magnetization is important for the estimation of iron loss of a dc-biased transformer, there are few reports of such magnetic properties measurements of a real laminated core; mainly because the measuring system of such magnetic properties is difficult to establish.

In this paper, a measuring system for the magnetic properties of GO silicon steel lamination under dc-biased magnetization is proposed. The newly developed system has the advantage that there is no interplay between ac and dc excitations, both ac and dc excitation applied to the same exciting winding, making the control easy, compared with the usual technique using a ring core or SST, having ac and dc exciting windings[3], [4]. Moreover, the exciting mode of this system is fairly the same as the actual condition of the dc-biased transformers.

As is well-known, material properties measurements can contribute to the accurate computation of electromagnetic fields because that is where they are used. The purpose of this paper is to present a practical measurement method for the dc-biased magnetic properties of laminated cores, to investigate the effect of the variation of dc-biased magnetic field intensity on iron loss and flux in GO silicon steel sheets, and to find an efficient numerical approach to model the iron loss of dc-biased transformers using the obtained specific total loss curve.

II. MEASUREMENT OF MAGNETIC PROPERTY

The dc-biased magnetic properties measurements were carried out with the aid of the LCM, with 45°-mitred step-lap joints, made of GO silicon steel sheet 30Q140, as shown in

Fig.1. The experimental system based on the laminated core model is established as shown in Fig.2. The dc current passing through the exciting coil of the LCM supplied by the dc source is in series with the ac current.
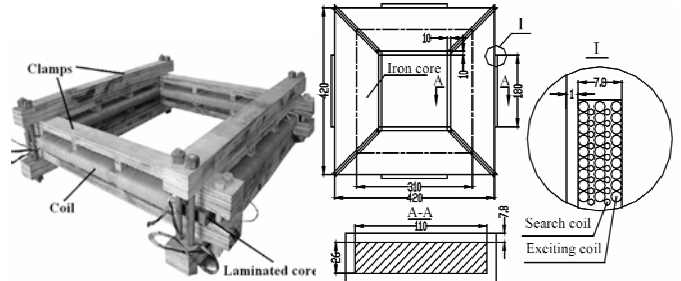
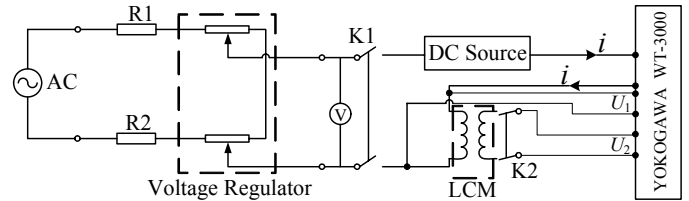

Fig.1. Laminated core model of product level.

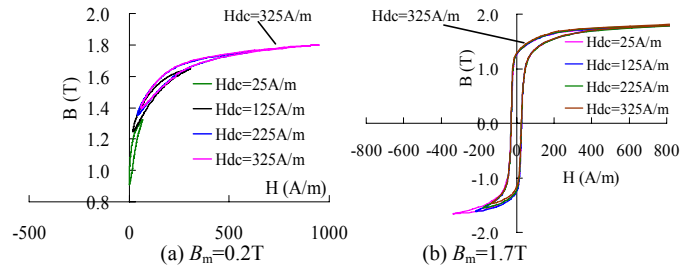Fig.2. Experimental system of dc-biased magnetic property.

(a) B_m=0.2T   (b) B_m=1.7T

Fig.3. Hysteresis loops (B_m is the amplitude of ac component of flux density).

The magnetic properties of the LCM are measured. Fig.3 shows the effect of dc bias on the B-H property. It illustrates that the area of hysteresis loop is increased when H_{dc} is large. As a result, the total iron loss under large dc bias is increased as shown in Fig.4.

(a) Specific total loss curve   (b) Iron loss (B_m=1.7T, 50Hz)
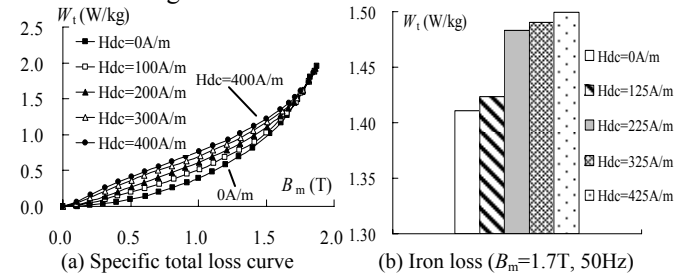
Fig.4. Iron loss under dc-biased magnetization (50Hz).

Fig.4 (a) gives the effect of dc bias on the iron loss at 50Hz. Fig.4(b) shows the comparison of total iron losses at different

H_{dc} (B_m=1.7T, 50Hz). For 30Q140 lamination, the total iron loss W_t at H_{dc}=425A/m is about 7% higher as compared to the total loss at H_{dc}=0A/m.

III. ANALYSIS OF IRON LOSS AND FLUX

Effects of variation of dc-biased magnetic field intensity H_{dc} and ac working magnetic flux density B_m on the iron loss and flux are examined in detail. The exciting mode of the LCM is listed in Table I.

TABLE I
DIFFERENT EXCITATION CONDITIONS

Cases	B_m(T)/H_{dc}(A/m)	Cases	B_m(T)/H_{dc}(A/m)
1	0.5/100	6	0.5/400
2	1.0/100	7	1.0/400
3	1.4/100	8	1.4/400
4	1.7/100	9	1.7/400
5	1.8/100	10	1.8/400

A. Treatment of Anisotropy

To effectively reduce the computation cost, the first few laminations are modeled individually as shown is Fig. 5(a). An air region is used to analyze the leakage flux in the surface layers. The inner laminated sheets are modeled as bulk and the electric conductivity (σ) is modeled as anisotropic [5], [6]. The tangential conductivity (y-z plane) is isotropic, but the normal conductivity (x-axis) is near to zero, as shown in Fig. 5(b).
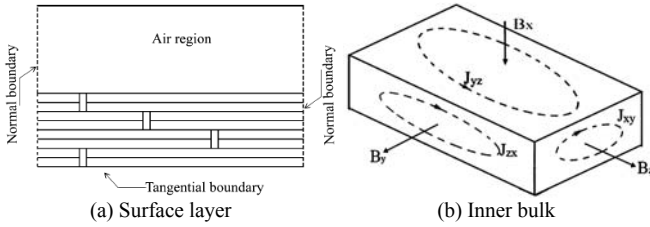

(a) Surface layer   (b) Inner bulk
Fig.5. 3-D simulation model.

The magnetic property of the GO silicon steel 30Q140 is certainly anisotropic, however, the applied field to LCM is almost along the rolling direction. Therefore, the working property of the LCM is, in fact, weakly anisotropic; so the measured specific total iron loss curve W_t-B_m and B_m-H_b curve are sufficient. In the T-Ω solver the eddy current region with the electric anisotropic and magnetic anisotropic material property can be basically formulated by (1),

$$\nabla\times\left(\frac{1}{c_p}\begin{bmatrix}\varepsilon\sigma_T & & \\ & \sigma_T & \\ & & \sigma_T\end{bmatrix}^{-1}\nabla\times T\right)+\begin{bmatrix}\mu_0/(1-c_p) & & \\ & c_p\mu_y & \\ & & c_p\mu_z\end{bmatrix}\frac{\partial(T-\nabla\Omega)}{\partial t}=0 \quad (1)$$

where $\varepsilon\ll 1$, and c_p is a packing factor of lamination structure, μ_0 is the permeability of air.

B. Modeling of Iron Loss

The eddy currents can be neglected in the electromagnetic analysis of the inner layer because the sheet is very thin (0.3mm thick). Of course, B_m obtained in this way will be somewhat different from the real flux density B_m. Fortunately, the measured specific total iron loss of the LCM already includes the eddy current loss induced by the planar flux.

When measuring dc-biased magnetic properties using the proposed measuring system, only the tangential excitation is applied; the flux sometimes enters the laminated sheets perpendicularly and that leads to an extra eddy current loss which is referred to as an additional iron loss; the eddy current reaction from such excitation condition is however much lower and can be neglected.

Therefore, the total iron loss $W_{lamination}$ inside the GO silicon steel sheets lamination at the specified H_{dc} can be calculated by (2),

$$W_{lamination} = \sum_{e=1}^{NE}\left[W_t^{(e)}(B_m^{(e)})\right]V^{(e)} \quad (2)$$

where $B_m^{(e)}$ and $V^{(e)}$ are the peak value of the flux density along the rolling direction inside the LCM and the volume per element, respectively. NE is the total number of elements in the laminated sheets. $W_t^{(e)}$ is the total iron loss per element. It is a function of B_m and ΔB due to the dc-biased magnetization. A post-processing method for establishing the relationship between W_t and B_m (without ΔB) is proposed, as shown in (3), producing the measured W_t-B_m curve, mentioned-above.

$$B = \frac{B_{max} - B_{min}}{2} = B_m \quad (3)$$

where $B_{max} = B_m + \Delta B;\quad B_{min} = \Delta B - B_m$, as shown in Fig.6.

Note that, the measured W_t-B_m curve at the specified H_{dc}, in Fig.4 (a), is used in the field computation; i.e., the effect of dc-biased magnetic field intensity H_{dc} on the total iron loss is already included in (2). Finally, the total iron loss $W_{lamination}$ of (2) could turn out to be the function of B_m and H_{dc}.
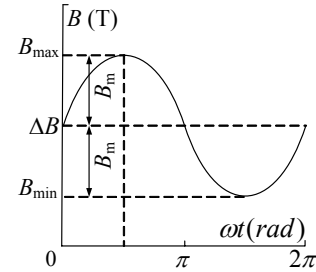

Fig.6. Definition of B_{max}, B_{min} and B_m under dc bias.

IV. RESULTS AND DISCUSSION

Table II shows a good agreement between the measured and calculated iron losses for each test case. This proves that the proposed practical approach is effective in dealing with the dc-biased lamination configuration.

TABLE II
TOTAL IRON LOSS UNDER DIFFERENT EXCITING CASES

Iron loss (W/kg)					
Cases	Measured	Calculated	Cases	Measured	Calculated
1	0.2654	0.2437	6	0.4034	0.3696
2	0.6122	0.5715	7	0.7555	0.7202
3	0.9787	0.9186	8	1.1038	1.0749
4	1.4388	1.3665	9	1.5034	1.4392
5	1.7152	1.6483	10	1.7487	1.6962

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