Influences of Isotropic and Anisotropic Magnetostriction on Three-Phase Transformer with Highly Grain-Oriented Electrical Steel Sheet

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***Abstract*—This paper investigates the influence of the anisotropic magnetostriction on a three-phase transformer made of a highly grain-oriented electrical steel sheet. To clarify the effect of the anisotropic magnetostriction, the numerical results by the isotropic and anisotropic magnetostriction models are presented, and are compared to the local magnetostriction measured in the three-phase transformer model.**

***Index Terms*—Highly grain-oriented electrical steel sheet, magnetostriction, three-phase transformer.**

I. Introduction

In recent years, the development of a high-efficiency transformer with low-noise has been required to solve global environment problems. To achieve this demand, the recent transformers are constructed by a highly grain-oriented electrical steel sheet (ESS) having smaller iron loss and magnetostriction than a grain-oriented ESS.

The highly grain-oriented ESS has quite strong anisotropic magnetic properties with respect to the directions of applied magnetic flux density. In the forgoing researches on the magnetic field analysis of the transformer, the influences of the anisotropic magnetic properties have been investigated, and it is clearly concluded that the anisotropic magnetic properties of the ESS should be considered for the accurate magnetic field analysis of the transformer [1].

The highly grain-oriented ESS also has the anisotropic magnetostriction properties, which are generally expressed as a function of the magnetic flux density [2], [3]. In the transformer by the highly grain-oriented ESS, most magnetic fluxes may flow through the rolling direction (RD) of the ESS due to anisotropic magnetic properties. From this point of view, the magnetostriction by magnetic flux along the transverse direction (TD) is not affected to total magnetostriction in the transformer. The influence of the anisotropic magnetostriction on the transformer should be, therefore, reported distinctly for the efficient magnetostriction analysis.

In this paper, the numerical results by the isotropic and anisotropic magnetostriction models are presented to clarify the influences of the anisotropic magnetostriction on a three-phase transformer with a highly grain-oriented ESS. The magnetic field, which is a source of the magnetostriction, is analyzed utilizing *B-H* curves along the RD and the TD of the ESS. In order to verify influences by the isotropic and the anisotropic magnetostriction models, the numerical results are compared to the local magnetostriction measured experimentally in a three-phase transformer model.

II. Magnetic Field Distribution by Anisotropic Magnetic Property in Three-Phase Transformer

Fig. 1 compares the *B-H* curves measured along the RD and the TD of a highly grain-oriented ESS (30PH105). Since the highly grain-oriented ESS has much higher permeability along the RD than the TD, its anisotropic magnetic properties should be taken into account for the magnetic field analysis.

In this paper, a simple anisotropic magnetic model is applied to consider the anisotropic magnetic properties [1], and is formulated as follows:

$$\begin{Bmatrix} H_{RD} \\ H_{TD} \end{Bmatrix} = \begin{bmatrix} \nu_{RD} & 0 \\ 0 & \nu_{TD} \end{bmatrix} \begin{Bmatrix} B_{RD} \\ B_{TD} \end{Bmatrix} \tag{1}$$

where ν_{RD} and ν_{TD} are the reluctivities along the RD and the TD of the ESS, respectively, and *B* and *H* are magnetic flux density and field intensity, respectively. The reluctivities along the RD and the TD are obtained from the *B-H* curves shown in Fig. 1.

Fig. 2 shows an three-phase transformer model which the applied voltage is 154($kV_{L\text{-}L}$). The transformer is constructed by the highly grain-oriented ESS (30PH105), and does not have the secondary winding.

Fig. 3 shows the magnetic flux distributions at different analysis times. It is found that most of the magnetic fluxes flow through the RD of the ESS in the three-phase transformer, due to the strong anisotropic magnetic properties. Fig. 4 shows the ratio (B_{TD}/B_{RD}) between maximum RD and maximum TD components in a *B*-waveform, and it is observed that the TD component is relatively smaller than the RD one in the most regions expecting the small T-joint region.

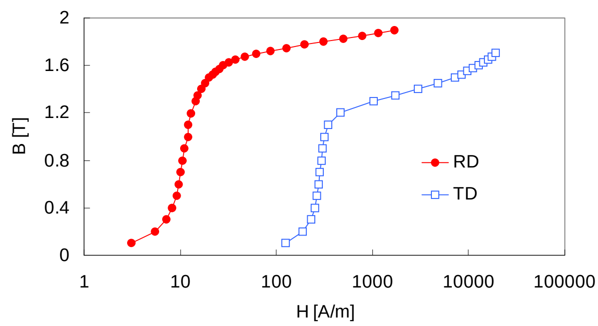


Fig. 1. *B-H* curves measured along the RD and the TD of a highly grain-oriented electrical steel sheet.

III. Magnetostriction by Isotropic and Anisotropic Models

Fig. 5 compares the magnetostriction properties according to the RD and the TD in the highly grain-oriented ESS, and it is found that the two magnetostriction curves are quite different. If the magnetic flux flows through not only the RD but also the TD, the anisotropic magnetostriction should be considered to magnetostriction analysis of the transformer.

In a practical three-phase transformer with the highly grain-oriented ESS, most of the magnetic fluxes pass through the RD as shown in Fig. 3 and 4. Therefore, the importance of the anisotropic magnetostriction cannot be emphasized explicitly for magnetostriction and vibration analyses.

In order to investigate the influences of the anisotropic magnetostriction, the isotropic and anisotropic models are applied to the magnetostriction analysis of the three-phase transformer with the highly grain-oriented ESS.

The isotropic model is represented as follows [4]:

$$\lambda_{x'} = \lambda\left(\left|\vec{B}\right|\right),\quad \lambda_{y'} = -\lambda\left(\left|\vec{B}\right|\right)/2,\quad \lambda_{z'} = -\lambda\left(\left|\vec{B}\right|\right)/2 \tag{2}$$

where (x', y', z') is a local coordinate system which x' coincides with the direction of B, and λ is the magnetostrictive strain in the direction of B. Since most magnetic fluxes flow through the RD in the transformer, λ can be obtained approximately from the RD curve shown in Fig. 5.

The anisotropic model is explained as follows [4]:

$$\begin{aligned}
\lambda_{x''} &= \lambda_{RD}\left(\left|\vec{B}_{RD}\right|\right) - \lambda_{TD}\left(\left|\vec{B}_{TD}\right|\right)/2 \\
\lambda_{y''} &= \lambda_{TD}\left(\left|\vec{B}_{TD}\right|\right) - \lambda_{RD}\left(\left|\vec{B}_{RD}\right|\right)/2 \\
\lambda_{z''} &= -\lambda_{RD}\left(\left|\vec{B}_{RD}\right|\right)/2 - \lambda_{TD}\left(\left|\vec{B}_{TD}\right|\right)/2
\end{aligned} \tag{3}$$

where (x'', y'', z'') is a local coordinate system which x'' coincides with the RD, and λ_{RD} and λ_{TD} are magnetostrictive strains obtained from the magnetostriction curves along the RD and the TD shown in Fig. 5, respectively. If the B_{TD} is much smaller than the B_{RD} in (3), the anisotropic model can be approximated to the isotropic one. Therefore, it has a possibility to make little influence by the anisotropic magnetostriction. It should be verified clearly for the efficient magnetostriction analysis of the three-phase transformer.

In the version of full paper, the numerical results such as magnetostriction and magnetostrictive force will be shown in detail, and be compared to the local magnetostriction measured in a three-phase transformer model.

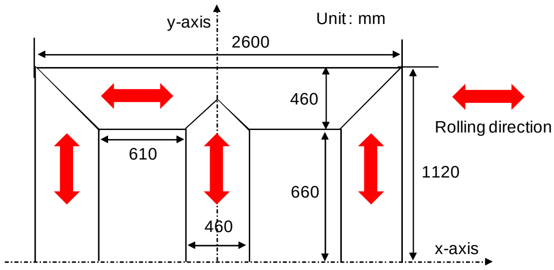
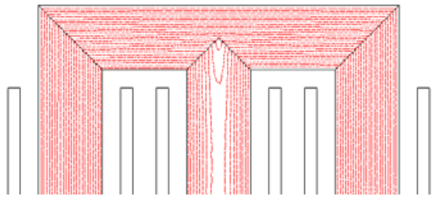
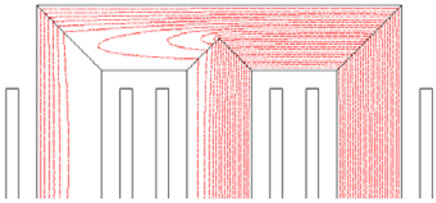


Fig. 2. An analyzed three-phase transformer model made of a highly grain-oriented ESS.



(a) $\tau = 0.39$ (rad)



(b) $\tau = 1.18$ (rad)

Fig. 3. Magnetic flux distributions of the thee-phase transformer model by the anisotropic magnetic properties of the ESS.

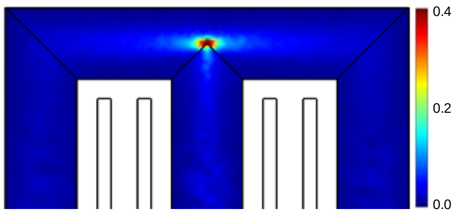


Fig. 4. Ratio between maximum RD and maximum TD components in the *B*-waveforms.

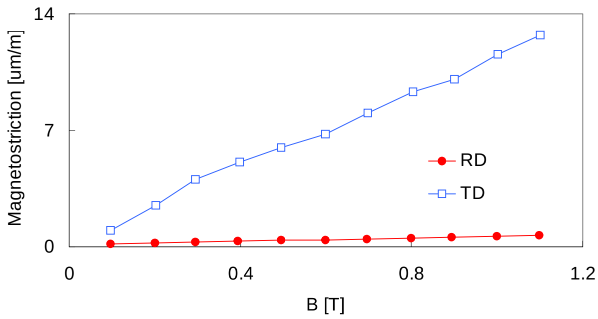


Fig. 5. Magnetostriction curves measured along the RD and TD of a highly grain-oriented electrical steel sheet.

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