# Anisotropy Influence on the Rotational and Alternating Field Behavior of Soft Magnetic Materials

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**Abstract-- Magnetic losses of three soft magnetic materials : GO SiFe, NO SiFe and cubic textured NiFe are measured under 50Hz sinusoidal and rotational induction conditions. It is found that, for the NiFe, the losses obtained under 1D or 2D excitations are always lower than the sum of the alternating ones measured along the rolling and transverse directions of the sheet. For the SiFe samples, the principle of superposition is just valid up to 1.0T. This behavior can be connected directly to the magnetocrystalline anisotropy of the material which is about thirty times higher for the SiFe than the NiFe and controls the magnetization processes.**

## INTRODUCTION

Standard characterization of magnetic materials used in electrical machines is nowadays inadequate to describe the magnetic behavior of the magnetic circuits, because it is limited to the rolling and transverse directions measurements. In fact, practically, magnetic properties of electrical steel, as B(H) curves or magnetic losses, differ with the direction of the applied field. Even non-oriented electrical steel is not an isotropic material and the different directions in the plane of the sheet are not equivalent. In addition, local analysis of the magnetic circuits of electrical machines points out complicated distributions of the magnetic flux. In some particular areas of three phase transformers or rotating machines for instance [1], rotational field distributions are generated due to the shape of the circuit. Under such conditions, magnetic properties are also far from those measured in alternating field.

Precise calculations of the electrical machines require a correct determination of the field distribution in each area of their magnetic circuits and a knowledge of the magnetic properties in the corresponding working conditions, i. e. a complete characterization of the magnetic material in 1D and 2D exciting field. Nowadays, no analytical or numerical modelization can provide a complete representation of the magnetic material behavior because the magnetization proccesses which take place are very complex.

However, pure iron and silicon steels are characterized by a high magnetocrystalline anisotropy. So the main axes of the sheet (the rolling and the transverse directions) are well documented. Their magnetic properties in unidirectional field are generally well known. This paper discusses the validity of the hypothesis that any other 1D or 2D magnetic properties can be deduced from these classical characteristics. For this purpose, magnetic losses obtained in rotational and alternating exciting field are analysed in order to study the infuence of the magnetocrystalline anisotropy in these mechanisms.

## TEST SPECIMENS AND EXPERIMENTAL CONDITIONS

Three kinds of soft magnetic materials with different textures and magnetocrystalline anisotropies are studied :

- a 0.35 mm thick conventional grain-oriented 3% silicon-iron sheet with a GOSS texture (GO),
- a 0.50 mm thick non oriented 3% silicon-iron sample (NO),
- a 0.34 mm thick double-oriented 50% nickel-iron sheet (cubic texture).

The saturation magnetization is 2.0T for the SiFe alloys and 1.6T for the NiFe one. They are both characterized by cubic lattices with an anisotropy constant $K_1 = +35000$ and $+1300\ \mathrm{J.m^{-3}}$ respectively. The easy direction of magnetization for the GO SiFe is the [001] and corresponds to the rolling direction of the sheet, when the NiFe sample has two easy axes ([100] and [010]) which are the two main directions of the sheet.

The three test samples are measured under unidirectional and rotational exciting fields. The experiments are achieved using a rotational loss measurement device and controling the waveform of the magnetic induction B: sinusoidal, circular or elliptical [2], [3], [4]. In this last case, measurements are made keeping constant the rolling direction component $B_x$ of the induction and changing the transverse component $B_y$. Tests are so defined by the axial ratio $a = B_y / B_x$. In every case the called rotational losses correspond to the quantity :

$$P_r = \frac{1}{\rho T}\int_0^T \left[H_x \frac{dB_x}{dt} + H_y \frac{dB_y}{dt}\right] dt$$

where ρ is the material density and T the period (50 Hz).

## MAGNETIC LOSS RESULTS

The magnetic losses of the three samples obtained under circular or elliptical inductions ($P_r$) are compared to those measured under sinusoidal working induction, applied along the rolling direction ($P_L$) and the transverse one ($P_T$). Figure 1 corresponds to the obtained results on the GO SiFe sample and shows that up to 1.0T, the rotational losses of this sample are the sum of the sinusoidal losses in the rolling and transverse directions. This decomposition is also valid for the NO SiFe sheet but only up to 0.8T (Fig. 2). Rotational losses of the NiFe sheet are systematically lower than the sum of the alternating losses of the rolling and transverse directions (Fig. 3).

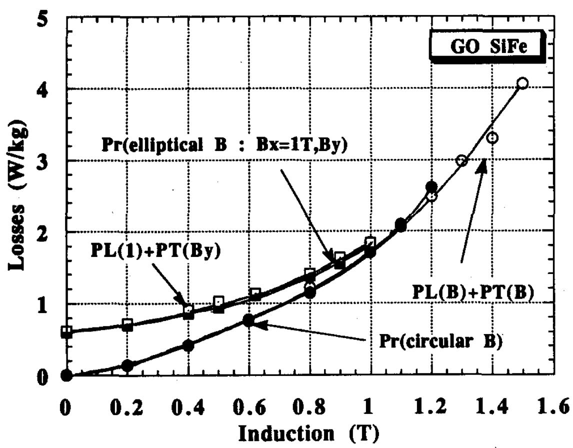


Figure 1 : Magnetic losses in alternating, circular and elliptical ($B_x$=1.0 T, $B_y$) conditions obtained for the GO SiFe sample

- ● $P_r(B)$ : circular B condition
- o $P_L(B)+P_T(B)$ : sum of classical rolling and transverse losses
- ■ $P_r(B_y)$ : elliptical B condition ($B_x$=1.0 T)
- □ $P_L(1.0\ T)+P_T(B_y)$ : unidirectional condition

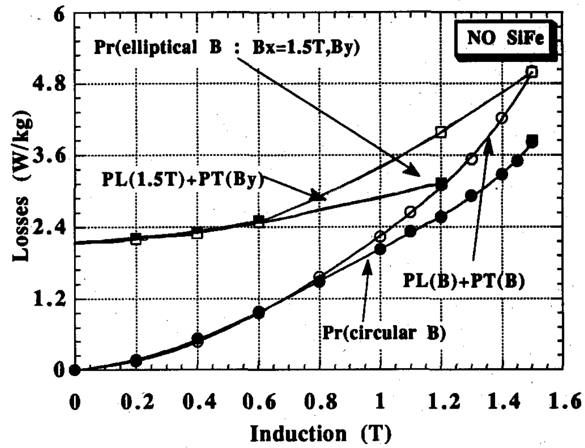


Figure 2 : Magnetic losses measured in different excitations for the NO SiFe sample

- ● $P_r(B)$ : circular B condition
- o $P_L(B)+P_T(B)$ : sum of classical rolling and transverse losses
- ■ $P_r(B_y)$ : elliptical B condition ($B_x$=1.5 T)
- □ $P_L(1.5\ T)+P_T(B_y)$ : unidirectional condition

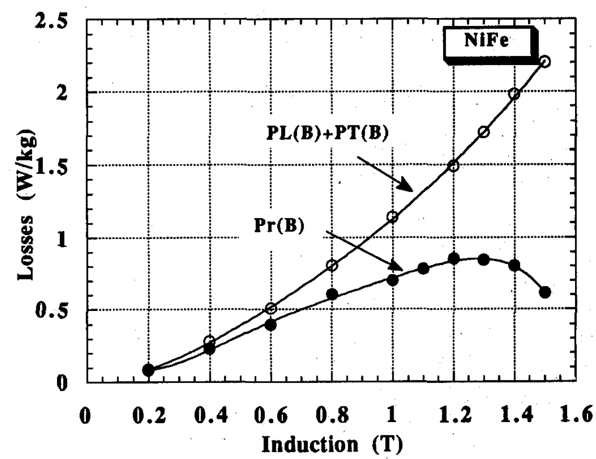


Figure 3 : Magnetic losses of the NiFe sheet obtained in circular and in sinusoidal induction (rolling and transverse directions)

- ● $P_r(B)$ : circular losses
- o $P_L(B)+P_T(B)$ = sum of unidirectional losses

The alternating magnetic losses ($P_\theta$) in different directions belonging in the plane of the sheet have been also determined for the NiFe where θ is the angle between the applied induction and the rolling axis. The measurements show that $P_\theta(B)$ are always 10 to 30% lower than the sum of its separated components $P_L(B_x)+P_T(B_y)$.

## DISCUSSION

In these experiments, all the magnetization processes are obtained controlling the sinusoidal components $B_x$ and $B_y$ of the induction vector (amplitude and phase). Thus, for example, when the components $B_x$ and $B_y$ are fixed at 1.0T, the measurements conditions can be :

- an unidirectional and sinusoidal induction, with 1.4T amplitude applied at 45° from the rolling direction, if $B_x$ and $B_y$ are in phase,
- or a circular rotating induction of 1.0T amplitude if the $B_x$ and the $B_y$ are in quadrature,
- or an intermediate elliptical rotating induction.

The stated question can be then expressed as following : in which conditions, are the magnetization processes decoupled in such manner that the total losses obtained in rotational or any unidirectional excitation obey the superposition principle?

The three tested samples have, in theory, very different elementary domain configurations. This is due to their composition on one hand and to their texture on the other hand. The GO SiFe sheet presents big grains and large size domains well distributed along the rolling direction. In the NO SiFe sample, the composition is nearly the same but the texture is more complex and the grains are at least ten times smaller. Domains are then small and have variable directions. In these two sheets, the magnetocrystalline anisotropy of the material tends to keep fixed these domain orientations. All the magnetization changes can be explained, up to the approach to the saturation, by Bloch wall displacements.

At low induction levels ($B \leq 1$ T for the GO SiFe and $B \leq 0.8$ T for the NO SiFe), the domains which determine the $B_x$ variations are different from the $B_y$ ones. Therefore the superposition principle can be used [5], [6], [7]. At higher induction (which are the usual working conditions in electrical machines) the experiments show that the decomposition of the rotational losses into the alternating ones along the rolling and transverse directions is no larger valid.
In the NiFe sample, the low anisotropy of the material cannot block the magnetization axes of the domains. Rotational processes take place involving a coupling between the magnetization in the rolling and transverse directions. So the rotational losses are systematically lower than the sum of losses $P_L(B)+P_T(B)$

## CONCLUSION

The magnetocrystalline anisotropy affects the magnetization mechanisms either in unidirectional and rotational field. In the two studied SiFe samples, 1D and 2D losses can be deduced from the unidirectional rolling and transverse ones only at very low inductions. In usual working conditions of the industrial magnetic circuits, the superposition principle cannot be used.

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