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ANISOTROPY OF STEEL SHEETS AND CONSEQUENCE FOR EPSTEIN TEST: II EXPERIMENT

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Abstract: It has been showed that the mathematical theory of ODF can be employed to estimate anisotropy of magnetic properties. The obtained results suggest that the current Standard should include the measurement at three directions - 0^o, 45^o, 90^o in relation to the Rolling Direction (RD) - and that the average of properties can be estimated from these measurements.

Keywords: electrical steels, anisotropy, ASTM Standard.

1. INTRODUCTION

Non-oriented electrical steels are employed in electrical motors. Among the most relevant properties commonly evaluated are the magnetic inductions B_{25} and B_{50}, iron losses and magnetic permeability.

In the previous paper [1], a theory for describing the anisotropy of electrical steels was developed. That theory predicts that an expression of the type $A_o = (A(0^o)+A(90^o)+2A(45^o))/4$ – where A is an arbitrary variable - can describe, at least as first approximation, the average magnetic properties of a steel sheet, because the existence of symmetries - the crystalline symmetry (bcc iron cubic symmetry) and the orthorhombic sheet symmetry.

2. TEST OF THE MODEL

Using the theory described in the previous paper [1], where equation (1) was demonstrated, the magnetic properties: induction B_{50} and B_{25}, iron losses P(15/60) at 1.5T, 60Hz and magnetic permeability μ_{15} were estimated (see equations 2-5)

$$A = A_o + A_1 \cos(2\beta) + A_2 \cos(4\beta) \quad (1)$$

$$B_{50} = 1.6845 + 0.0357 \cos(2\beta) + 0.0468 \cos(4\beta)\ (T) \quad (2)$$

$$B_{25} = 1.5903 + 0.0400 \cos(2\beta) + 0.0487 \cos(4\beta)\ (T) \quad (3)$$

$$P(15/60)=4.7866-0.4517\cos(2\beta)-0.2514\cos(4\beta)\ (W/kg) \quad (4)$$

$$\mu_{15} = 1157.7 + 670.15 \cos(2\beta) + 484.7 \cos(4\beta) \quad (5)$$

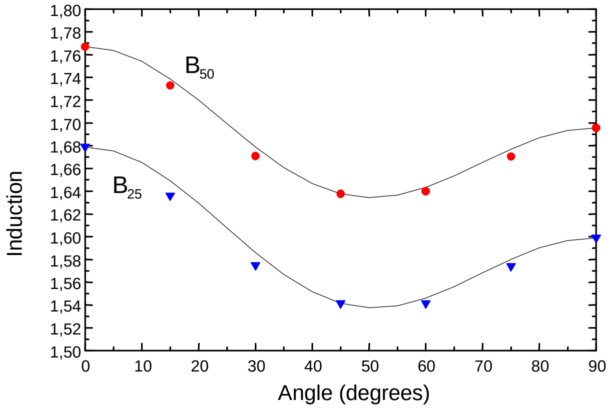

Figure 1 Experimental values for B_{25} e B_{50} (points) compared with values from equations (2) and (3) (full lines).

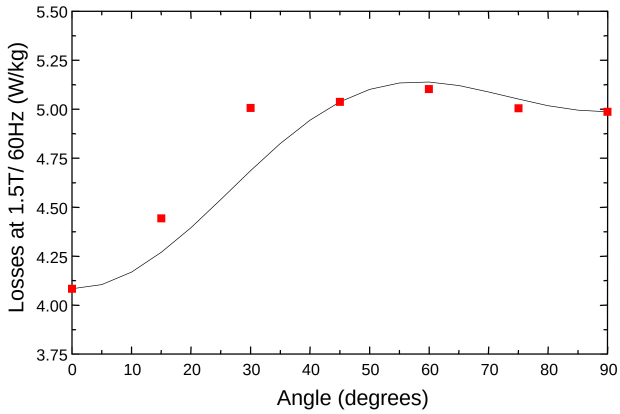

Figure 2 Experimental results for iron losses at 1.5 T / 60Hz (points) compared with equation (4) (full line).

Equations (2-5) are compared with experimental data in the figures 1, 2 and 3. The experimental points for 15^o, 30^o, 60^o and 75^o allow verify the reliability of the estimation.

It can be seen in the figure 1 the big accuracy of equations (2) and (3) for describing the variation of magnetic function as function of the angle.

However, for iron losses (figure 2) and permeability (figure 3), the adjust is not perfect. Even so, equations (4) and (5) can be used as indication of the behavior of those properties – losses and permeability - as function of angle. Most important, the average value (A_o of equation (1)) is in reasonable agreement. It should be remembered that μ_{15} and iron losses are function of many other microstructural parameters, besides texture and that the ODF model [1] includes only texture as microstructural variable.

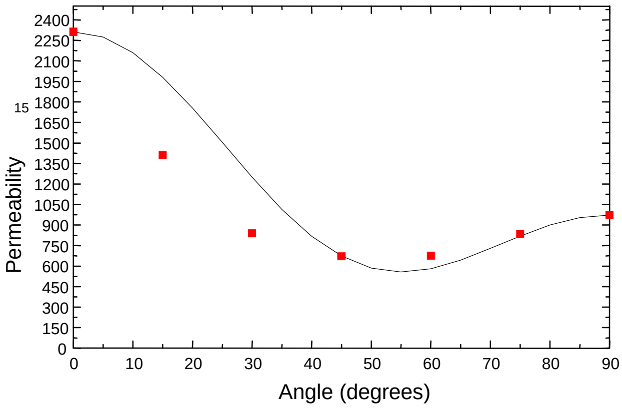

Figure 3 Experimental results for permeability μ_{15} (points) compared with equation (5) (full line).

It is very important to mention that the average values for B_{25}, e B_{50} e μ_{15} (equations 2, 3 and 4) are very near the measurements performed in sample rings, which eliminates anisotropy. Initial magnetization curve measured in a ring is showed in the Figure 4.

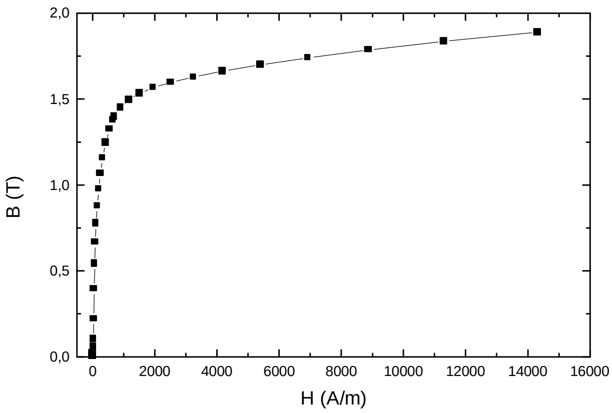

Figure 4. Initial magnetization curve measured in a ring.

In the figure 4, we obtain, for the ring, B_{25} = 1.60T, B_{50} = 1.69T, μ_{15}=1000. For the ring, the measured quasi-static losses was Pqe 391 =J/m^3. This value, converted to 60Hz Hysteresis Losses W/kg (conversion done multiplying by frequency (Hz) and dividing by the density (kg/m^3)) results in Hysteresis losses Ph=3.05 W/kg (for f=60Hz). This is very close to the average of the seven experimental points (3.02 W/kg), in the Epstein frame (see figure 5). The loss separation was performed according an already mentioned method [2]. The figure 5 shows that the effect of texture on the losses is mainly on the Hysteresis losses. The anomalous losses are almost not affected by the crystallographic orientation.

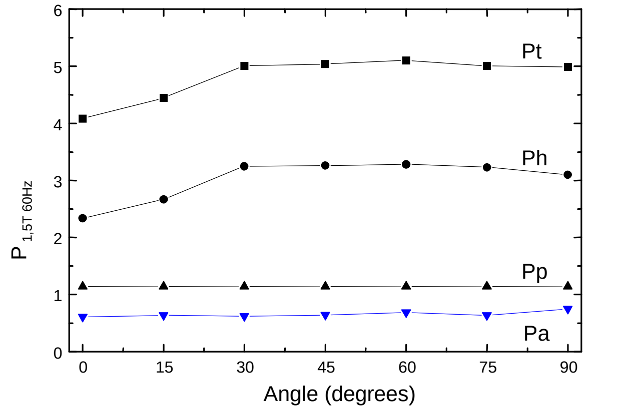

Figure 5. Losses - total, hysteresis, eddy and anomalous as function of the angle to RD. B=1.5T, f=60Hz. Epstein.

The obtained results showed the accuracy of expression (1), and that equations (2-5), obtained from equation (1) can give a reasonable estimate of the anisotropy of properties. It can be inferred that 3 separate measurements in the RD, TD (i.e., 90^o) and 45^o directions give a better estimate of the magnetic properties that the suggested by ASTM Standard A343 [3], where a (50%RD+50%TD) arrangement is suggested (ASTM Standard A 343 specifies: “for specimens cut half with and half cross grain, arrange all the parallel or “with-grain” strips in two opposite solenoids and all the cross- or transverse-grain strips in the other two opposite solenoids”). The Brazilian Standard NBR 5161 [4] includes suggestion similar of ASTM A 343 [3].

3. CONCLUSIONS

The formula A_o = (A(0^o)+A(90^o)+2A(45^o))/4 allow a very good estimate for inductions B_{50} and B_{25}, and a reasonable estimate for iron losses and permeability μ_{15}. These A_o values were compared with ring measurements results, and the agreement was also good. As a way to improve the current standard, it is suggested that the traditional Epstein arrangement (50%RD+50%TD) be changed for 3 separate measurements in the RD, TD (i.e., 90^o) and 45^o directions, and that the value of the property be given by the formula above.

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