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Magnetic Materials Characterizations Device under Rotating Field Based on Experimental Set up Approach

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Abstract: It is important to be able to characterize magnetic materials under the effect of a rotating field and to specify the influence of anisotropy. In this goal, different methods are used classically. In this study we describe the main features of a novel set-up for the determination of rotational hystérèsis power losses in soft magnetic materials. The flux search coil has 2 windings wound along diagonal lines of a square insulator into which the specimen is inserted, addition and subtraction of two output voltages from these winding give the signals proportional to the flux change rate in the direction parallel and transverse to the longitudinal direction of the ribbon .therefore two values of loss corresponding to two magnetizing directions are obtained using a numeric acquisition and measurement result treatments. A non oriented 3.5% silicon-iron power loss measurements in a very large induction range, are reported.

Key words: Rotational field, hystérèsis rotational loss, soft magnetic materials, rotating field device

INTRODUCTION

The most recent studies concerning distribution of magnetic induction in rotating electric machinery confirm that, in an important part of magnetic circuits some rotating magnetic fields exist.

Thus, in the case of stators machinery to alternating current, the field is rotating to the foot of the teeth, whereas it is united axial to the forefront of the teeth (radial) and to the back of the breech (tangential); the passage from a system to the other takes place through the intermediary of elliptic fields (Boon and Thompson, 1965; Anthony and Bleddin, 1973).

In a general way, fixed fields and rotating fields coexist in major part of electric devices (Boon and Thompson, 1965). It is therefore, important to be able to characterize materials under rotating field effect and specify influence of anisotropy. In this goal, different methods are used classically.

Among these, some require a shape adapted of the sample (disk), their stake some it is case of technique based on the principle of the angular pendulum for studies of anisotropy (Imamura *et al.*, 1985) or of the method consisting in submitting sample possessing two degrees of freedom (rotation transfer), bound of an axis to the action, of an alternative field. In this last case, magnetic features are calculated from measures made with the help of probes in effect Hall. This device permits to study either the anisotropy, either the losses under rotating field (Zouzou, 1991; Aouli *et al.*, 1996).

To determine the electromagnetic losses, a method consists in measuring the warming-up of sample with a thermocouple. Response signal, after amplification, is recorded on a drawing table. One deducts the losses that are proportional to slope at origin of representative curve of warming-up according to time (Boon and Thompson, 1965; Anthony and Bleddin, 1973).

This technique requires a very precise measure of elevation speed of temperature and the determination of the mass heat of the samples. Measure of temperature sample provides an absolute value of dissipation power to application point thermocouple (Fiorillo and Rietto, 1988).

Determination of losses in samples requires a number important of measures, in order to get a meaningful average value.

EXPERIMENTAL DEVICE

Device that we study is based on creation of rotating magnetic field with two operating coils in quadrate and supplied in order to impose two sinusoidal inductions orthogonal with same amplitude. This system permits to characterize samples presenting as ribbons. Losses determination corresponding to existence of rotating field is done from electric sizes voltages and currents.

In this study, we describe experimental device and solutions kept to control parameters and satisfy specifications. We treats the clarification of method of

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measure and characterization of anisotropy of samples. In particular, are presented and debated the relative experimental results to traditional alloys; measurement of magnetization in quadrate directions to improve the set-up device. In conclusion, we finishes by a characterization of a non oriented 3.5% Si-Fe under rotating field in a very large induction range for which we presents some results concerning losses variation according flux density.

At this time of survey, we meet various problems that are not again entirely resolute. The most delicate is the existence of a demagnetizing field according to transverse direction of the ribbon tested and the blossoming of lines induction in the same direction.

Predetermination of electromagnetic losses in electromagnetic devices is difficult because of a simultaneous presence of magnetic alternative fields and rotating fields in different regions of magnetic circuit. Besides in, of other places of circuit, they are submitted to stationary direction fields, different from the one of easy magnetization. It is therefore, interesting to determine electromagnetic losses in subject sheet metal in rotating field, but also, when they are submitted to alternative field applied in longitudinal or in transverse direction.

The main difficulties met concern definition of ribbon zone under rotating field, as well as the existence of a demagnetizing field and the blossoming of the induction lines in the transverse direction of the ribbon.

Rotating field device "Permeameter": It's constituted by two magnetic circuits c_1 and c_2 (Fig.1), perpendicularly disposed. Every magnetic circuit is composed by two symmetrical breeches achieved from a ferromagnetic core of which nature and geometric measurements must be chosen appropriately. Indeed to have a device functioning in the best conditions, it is necessary that the d. d. p. magnetic to the extremities of the ribbon to test either weakest possible. Excitations coils are nourished by two equal sinusoidal voltage orthogonally, to be sure to create a rotating field induction in central zone of the ribbon test; where the flux density detection coils are exactly bounded The components of magnetic field are deducted from measurement of primary currents.

Breeches choice: They must possess two essentially features:

- A most elevated relative permeability μr according low induction, so that their reluctance can be disregarded before the one of ribbon test. It permits to suppose then that the d. d. p. magnetic field in the ribbon is joined to the m. m. f.
- Sufficiently low electromagnetic losses so that they can be disregarded before those in the sample.

The choice is carried then on ferrite marks FERRINOX B50

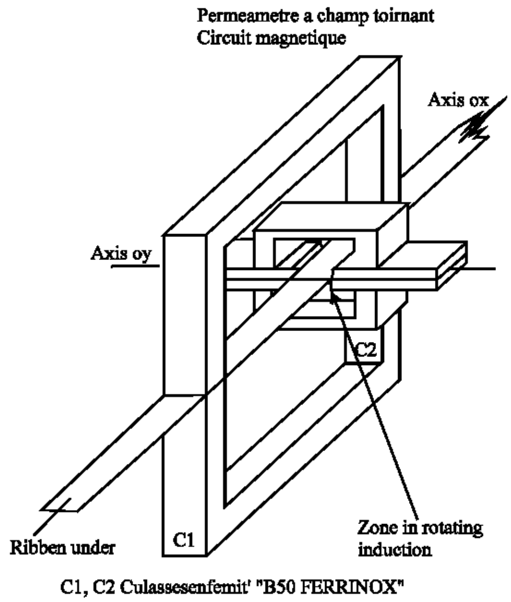

Fig. 1: Experimental device "Permeameter"

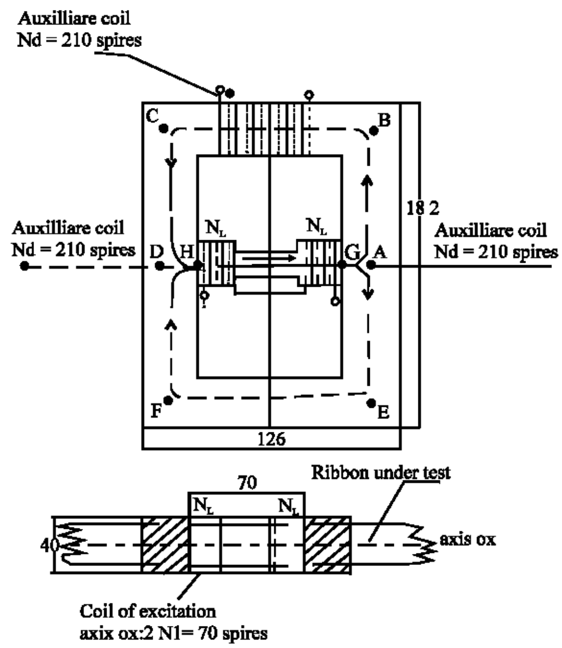

Fig. 2: Excitation circuit according to OX axis

Excitation circuit according to OX axis: It is constituted by two coils of N_l spires each, connected in series and rolled up so that their magneto-motrice forces is added (Fig. 2).

The winding so constituted creates a magnetic field oriented in the longitudinal direction of ribbon test.

Excitation circuit according to OY axis: It's is constituted by 04 coils of N_t spires each, connected in

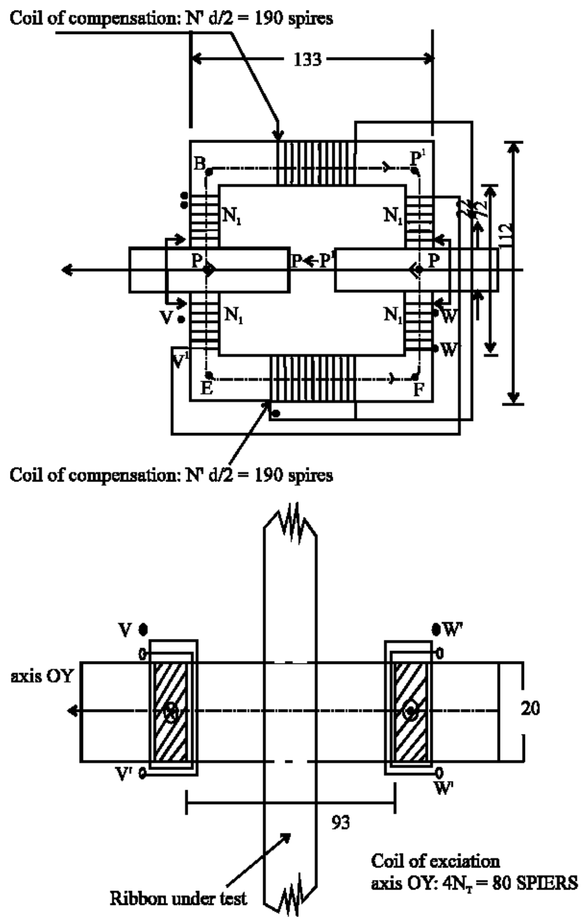

Fig. 3: Excitation circuit according to OY axis

series and rolled up around the two breeches in U(Fig. 3). Their magneto-motrice forces create a magnetic field oriented in the transverse direction of the ribbon test.

MAGNETIC FIELDS DETERMINATION

Without Eddy currents circulation, alternative field in the sample is uniform:

$$h(t) = \frac{2.N_L}{l} i(t) \qquad h(t) = \frac{2.N_R}{l'} i(t) \qquad (1)$$

Supply and measurement circuit: When Eddy currents circulation becomes considerable, there is an exclusion of flux lines and we consider expressions above, as giving the field in surface of the material to test. Otherwise, presence of an air gap produces a demagnetizing field that the curve of magnetization modifies, introducing a mistake to extent of field in the sample.

INDUCTION ROTATING VALUE DETERMINATION

Sensing coils induction are arranged in cross and surround the ribbon test, coiled according axes with angle $\eta = \pm \pi/4$.

Every spool possesses 10 spires; their numbers have been calculated in order to get amplitude signals sufficient at low inductions, in order to permit their treatment by the calculator. otherwise section of spools must be the most reduced possible, to minimize corrections on inductions measures.

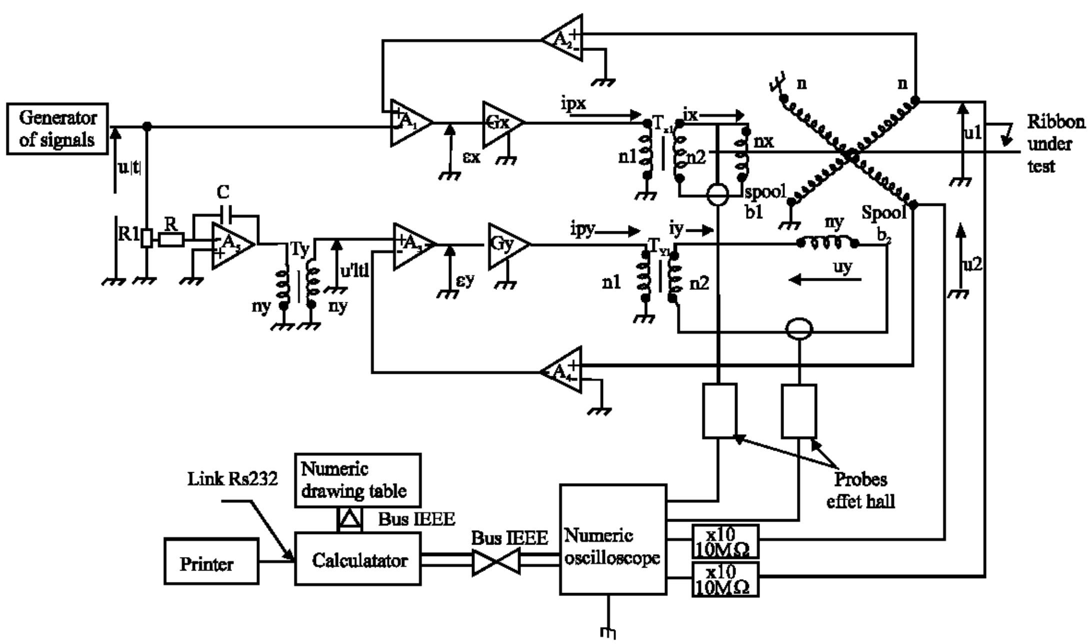

Fig 4 : Supply and measurement circuit

In the chosen geometry $\eta = \pm\pi/4$

$$\Phi_x(t) = \Phi_1(t) + \Phi_2(t)$$
$$\Phi_y(t) = \Phi_1(t) + \Phi_2(t) \quad (2)$$

$$u_1 = -n_1 S_x B_x \omega \sin(\omega t + \pi/4)$$
$$u_2 = -n_2 S_y B_y \omega \sin(\omega t + \pi/4) \quad (3)$$

To have a circular rotating field, it is necessary that:
$B = B_x = B_y$
We impose to the system therefore:
$U_1 = U_2 = U$
Varying amplitude voltage entry u' in the OY axis, otherwise in the chosen configuration has:
$S_x = S_y = S$
In these conditions

$$B = B_x = B_y = U / n.\ S.\ \omega \quad (4)$$

Supply and measurement circuit:
Represented in Fig. 4 is composed of:

- A variable frequency signal generator .
- Two differential amplifiers with adjustable gain and adjustable pass band.
- An amplifier with stationary pass band gone up in variable gain integrator
- Electronic circuits to operational amplifiers permitting to achieve the functions of amplification of the back chains from the OX and the OY axis.
- Separator transformers and an impedances adapters.

Obtaining a rotating field needs a servitude of the flux density and thus imposes that u_1 voltage and u_2 to the winding marks of the sensing coils are sinusoidal. In the same way, the installation is achieved in order to enslave these two sizes to two voltage of u and u' reference to satisfy the above stated conditions.

The excitations currents are measured with two probes in effect Hall.
U_1 and U_2 voltage, induced in detections spools are appropriated by two probes of impedances equal to 10 MΩ.

After acquirement numeric of i_x , i_y, u_1 and u_2, the calculator does the treatment by means of a software, that permits to calculate the magnetic and electric sizes.

LOSSES DETERMINATION

In many electro-technical equipment, exist some regions where B induction doesn't kept in a stationary direction but turns to the angular frequency Ω it is notably the case in the part of the electrical machines stator called: The foot of the teeth and also all the corners of a three phased circuit transformer. Magnetization mechanisms don't have anything to see then with those of an unidirectional magnetization The curve of the mass losses in field turning P'_{CT} is therefore, fundamentally different from the one of the losses in alternating field for the same frequency. The losses total P_T take into account the dissipations in each of the zones; one central station, subject to the rotating field, the two others, laterals where the induction, in a parallel and transverse direction, varies sinusoidal during the time.

$$P_T = P_{CT} + P_A \quad (5)$$

Calculation of the P_A losses: Has every measure one recovers the value of the B_X induction and one raises thecorresponding value of P_{XL} under fixed field what permits to determine the losses inattentive in the lateral area:

$$\overline{P}_A = P_{XL} \times S_X \times (1 - 1') \quad (6)$$

The losses under rotating field P_{CT}

$$\overline{P}_{CT} = P_T - P_{XL} \times S_X \times (1 - 1') \quad (7)$$

The volume losses correspond are:

$$P_{CT} = \frac{\overline{P}_{CT}}{1'^2 \times e_r} \quad (8)$$

The mass losses are:

$$P'_{CT} = \frac{\overline{P}_{CT}}{1'^2 \times e_r \delta} \quad (9)$$

MEASUREMENT RESULTS

In spite of care that we bring to the installation, it is not possible to eliminate the air gap existing between the ribbon under test and the breeches completely. A field demagnetizing whose influence is visible on the set of the features results from it. So, the magnetization curves measured and presented (Fig. 5 and 6) makes to appear an approach to the more rounded saturation than the one of the real features.

The measured losses are not affected appreciably by the presence of reasonable air gap, when induction remains sinusoid.

When the peak value of the induction is superior in 1, 5 T, servitude becomes little precise. it comes with a distortion of the tension wave and consequently, of an increase of the losses.

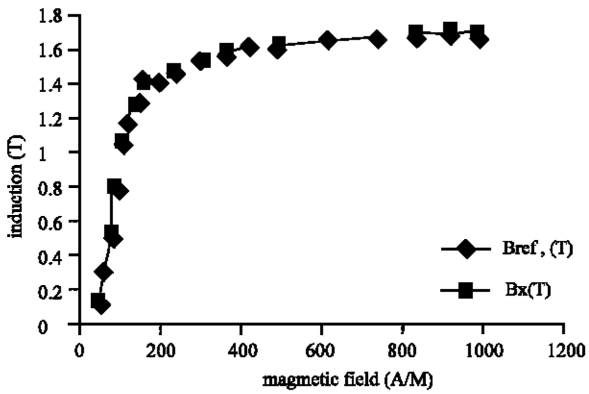

Fig. 5: Longitudinal alternating field magnetization at 400 Hz

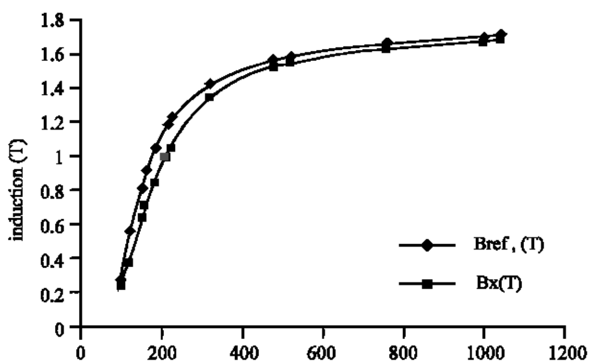

Fig. 6: Transversal alternating field magnetization at 400 Hz

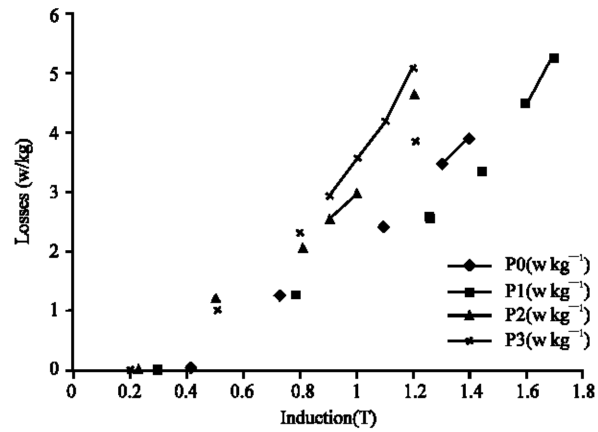

Fig. 7: Weight losses vs. induction f = 50Hz

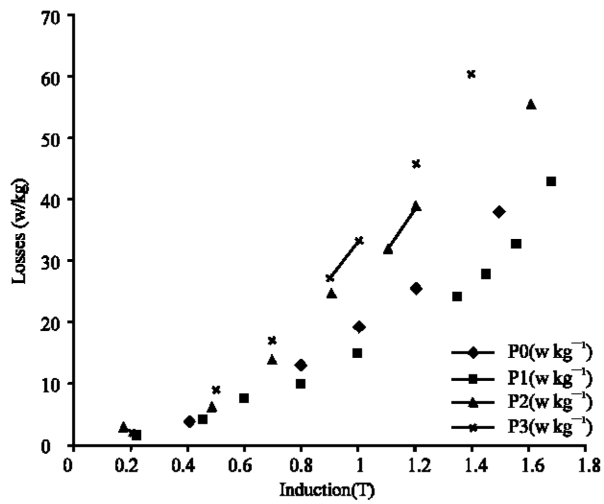

Fig. 8: Weight losses vs. induction f = 400 Hz

Rotating Field characterization: The object of this researsh is to compare the evolution of the losses qualitatively according to the induction in a ribbon ferromagnetic under rotating field and under alternative field.

Different problems have been met, with regard to the obtaining of the rotating field. Otherwise, all measures have been operated on a non oriented grain Fe-Si 3,5% of ribbon thickness 100 μm and the chosen trial frequencies are 50 and 400 Hz.

The mistake in the OX axis is of 2,4 % between the measured value and the one real, according to OY the mistake is of 16%. The previous measures show that the committed mistake enters the wanted securities and those really got are on the other hand negligible according to OX B_y in the OY axis is appreciably lower to the value of order. However for reasons of simplicity, the installation is adjusted in order to respect the $B_x = B_y$. It follows that to the breast of the material, the real induction turns elliptic way.

Besides the ideal conditions of induction servitude described previously are reached with difficulty because, beyond a certain value, the increase of the gain of the amplifiers provokes some instabilities; servitude becomes insufficient.

The existence of a field demagnetizing according to OY has the effect of increasing the value of the necessary applied magnetic field.

Rotating field loss determination: At the chosen 50 and 400 Hz frequencies, the values of the P_X and P_Y losses are got with the help of the calculator. The total losses: $P_T = P_X + P_Y$ in the ribbon is easily deducted.

In a second phase, for the value of the induction calculated B_x, one introduces in a file the value of the P_A losses (alternating field losses in the zone of the ribbon) raised on the P_A = f (B_x) curves, deducted of the volume alternating field losses P_{XL} with the help of the Eq. 6. The rotating field losses P_{CT} and the mass losses P'_{CT}, respectively definite by the Eq. 7 and 9 are finally calculated.

The presented curves (Fig. 7and 8) represent the fluctuation of the losses to 50 Hz and to 400Hz. the variations of the mass rotating field losses and alternating sinusoidal field (longitudinal and transverse) according to the B induction, for a non oriented Fe-Si 3,5% ribbon with 100μm of thickness.

To 50 Hz and for an induction lower to 0, 8T, the rotating field losses are appreciably equal to the sum of the alternating field losses according to the two perpendiculars directions; on can consider therefore, that the modifications of the magnetic domains remain very reduced and that a linear behaviour constitute a first reasonable approximation.

Beyond 0,8T, the losses under rotating field are weaker than the sum of the losses under alternative field of fixed direction; et the gap offers to become more pronounced with the induction.

To 400 Hz, the rotating field losses are appreciably equal to the sum of the losses under alternative field according to the two directions perpendiculars until 0,4 T. Beyond 0,4T, the rotating field losses are weaker than the sum of the alternative field losses of fixed direction; et the gap of 20% remained has constant meadows little then until the induction of 1, 2T and has the tendency to increase. These results seem astonishing, because the pace of the curve of the rotating field losses beyond 0,8T to 50Hz and beyond 0,4T to 400Hz some pace moves away from a foreseeable curve , when one compare it to the curve of the sum of alternative field losses according to the two directions (Fig. 9 and 10).

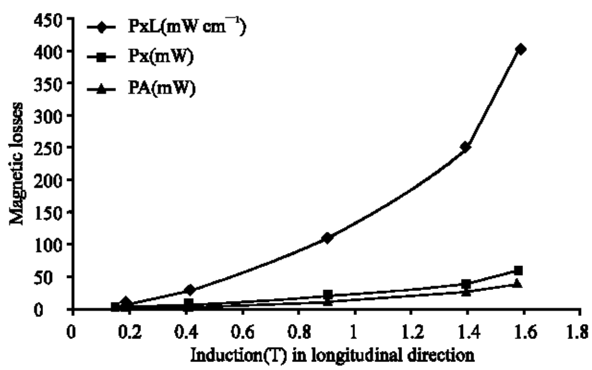

Fig. 9: Losses vs. induction in alternating field f=400Hz

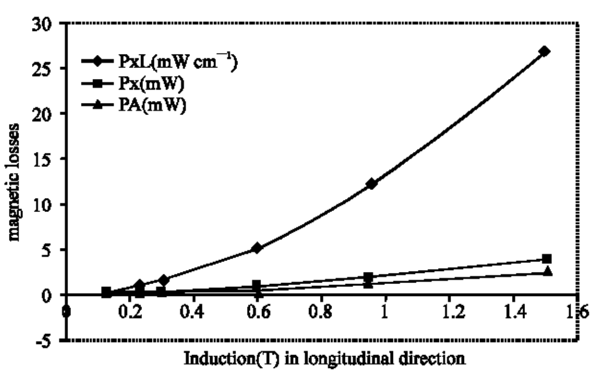

Fig 10: Losses vs. induction in alternating field characterisation f= 50Hz

CONCLUSION

This research permitted to achieve a magnetic properties characterization "permeameter" for ribbon sheet under rotating field and under alternating field (longitudinal and transverse). On measures, we essentially met two problems, one linked has the existence of the field demagnetizing, the other to the weak measurements of the samples.

The qualitative comparison between the characteristic B = f(H) according to the two longitudinal directions and transverse (Fig. 11) is possible if the tested samples have an identical shape and that one admit that the demagnetizing field according to the two directions of characterization. With regard to the losses, these are not affected by the existence of the demagnetizing field, if an acceptable limits exist. Nevertheless, it is necessary to be prudent in the interpretation of the results, because one cannot conclude as the material anisotropy, only from these parameters. Otherwise, the weak dimension sample characterization require to ascertain their homogeneity. In the case of the rotating field measures , except the presence of a demagnetizing field according to the axis transverse OY, other problems landed. The induction turns elliptic way according to the OX axis, the origin of error on the measure of B_x is due to the presence of the mobile breeches situated in the OY axis.

It is a neglected error, the value of measured B_x being practically equal to the one wanted. On the other hand, according to the OY axis, there is beyond a certain

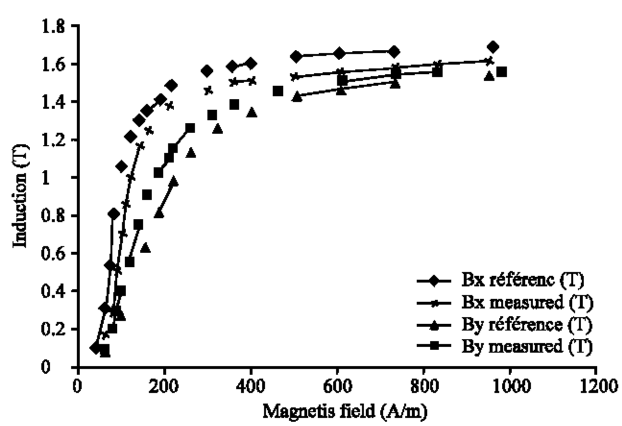

Fig. 11: Magnetization curves in orthogonal directions

induction (0,6T), a induction blossoming lines through the ribbon. It results by a mistake, for excess, on the measure of the B_y induction. Also the B_y induction is appreciably lower than the value of order. Otherwise, with regard to induction servitude, the two voltages of u references (OX) and u' (OY) remain simultaneously function of the voltages of outlays u_1 and u_2 of the two sensing coils; it is essentially this interaction that makes difficulties to obtain ideal induction servitude conditions. To bypass that, it would be necessary to arrange, on each of the two axes, two independent flux sensing coils. The set of these problems explains the difference met between the rotating field losses measured curves and the curve waited.

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