IMPROVED EVALUATION OF LOSSES IN SOFT MAGNETIC MATERIALS

S. MOTOAŞCĂ[1] E. HELEREA[1]
I.D. OLTEAN[1] G. SCUTARU[1]

Abstract: *The magnetic steel sheets are used for more than 100 years in various applications at the frequency of 50 or 60 Hz. Along with extension of the working frequency required by electronic devices development, new challenges have emerged for this class of materials. Current researches are aimed at rising their performances in order to be used in a broad frequency range. This paper deals with an analysis of the total losses which occur in grain oriented FeSi alloy sheets in order to establish the magnetic losses for broad frequency range. The program proposed in this paper can produce interpolation and extrapolation of experimental data in order to determine the total losses for different values of frequencies or magnetic induction.*

Key words: *FeSi alloy, chemical composition, magnetic properties, high frequency.*

1. Introduction

Electrical sheets are the soft magnetic materials mostly used in appliances from the beginning of electrical engineering development. Even now the research is aimed at improving the magnetic characteristics of FeSi sheets [1-5] in order to use these materials in broad ranges of frequencies needed in power control.

If magnetic performances for FeSi sheets (magnetic saturation induction B_{sat}, coercivity H_c) are satisfactory, the magnetizing efficiency should be improved. Losses in soft magnetic materials, especially in FeSi sheets, are relatively large and grow dramatically with the rise of the magnetic flux density and the frequency.

The trend for designers and manufacturers of electrical machines is to make smaller sized machines leading to the increasing values of magnetic flux density.

The development of power electronics requires a rise of working frequency of the electrical equipment with magnetic cores.

These tendencies lead to rise of the losses in magnetic materials.

2. Material under Study

The material under study (TI) is produced by the FEMAG Italy.

Table 1

The manufacturer's parameters for H and B

MATERIAL	QUALITY	THICKNESS [mm]	FREQUENCY [Hz]	MAGNETISING FIELD Heff. [As/cm]	MIN. INDUCTION Tesla
G.O.	M5T23	0.23	50	0.03	0.055
				0.3	1.3
				10	1.7

[1] Dept. of Electrical Engineering, *Transilvania* University of Braşov.

The soft magnetic materials are grain oriented (G.O.) electrical steel sheets with a content of 2.5% Si.

In Table 1 the manufacturer's parameters for electric field and magnetic induction for these materials are presented.

3. Experimental Details

Magnetic measurements have been made using the Epstein frame method. The FeSi samples, have been cut at the dimensions of 300x30 mm, and were placed evenly in the Epstein frame.

For measuring of the magnetic characteristics in the field of frequency between 1-600 Hz, the measurement system type DEM 25 (Brockhaus Messtechnik-Germany) with the Epstein frame of 100 windings was used.

The measurement method corresponds to IEC 60404-2 international standard, applicable to oriented and non-oriented grain electrical sheets, at measuring frequencies up to 1.5 kHz using Epstein frame method.

It is to be specified that with the used device the characteristics are determined for sinusoidal induced electromotive forces for specified peak values of magnetic polarization.

The magnetic polarization *J* and the frequency *f* have been programmed using the MPG software included in the equipment. Several magnetic parameters have been obtained automatically by the processor of installation after the simultaneous measurement of the current from primary winding and the magnetic flux acquired from secondary winding.

The MPG program has the capability to draw several types of magnetic curves and store the measurement results.

The measurement data stored in MPG program was exported in Excel program and the following curves have been obtained:

- magnetic induction versus magnetic field strength $B_m(H)$;
- magnetic permeability versus magnetic field strength $\mu_r(H)$;
- hysteresis curves $B(H)$;
- magnetic power losses dependence on frequency $p(f)$.

4. Results and Discussions

4.1. The Fundamental Magnetization Curve $B_{max}(H_{max})$ for f = const.

The magnetic dependence $B_m(H)/f = const.$ for grain oriented FeSi sheets samples at frequencies f = 100, 400 and 600 Hz are shown in Figure 1.

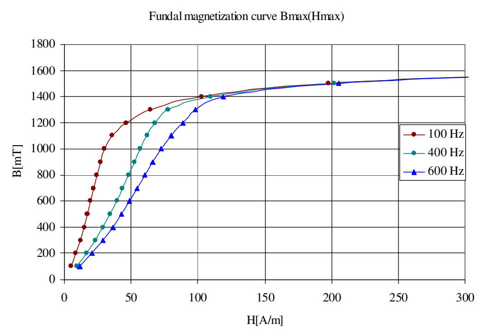

Fig. 1. *$B_{max}(H_{max})/f = const.$ for oriented FeSi strips of 0.23 mm (TI sample) at 100, 400 and 600 Hz*

From this figure it can be observed the decreasing of slopes in origin with the increasing the frequency of the magnetic field.

4.2. The Magnetic Permeability Dependence μ_r(H)

Figure 2 shows the magnetic permeability dependence on the magnetic field strength for sheets samples for several frequencies ranges between 100 and 600 Hz.

The increasing magnetizing frequency causes growing eddy currents and thus requires a further rise of the magnetic field to obtain the same values of magnetic flux density. This causes the modification of the relative magnetic permeability with frequency.

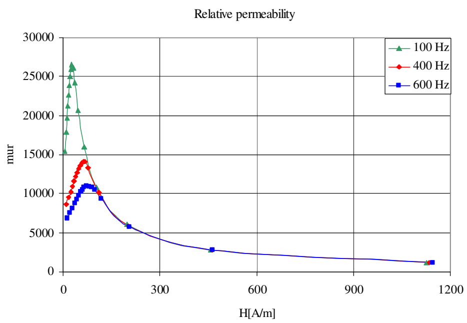

Fig. 2. *The relative permeability dependence $\mu_r(H)$ for f = 100…600 Hz*

It can be observed that the relative magnetic permeability decreases with the frequency.

4.3. Hysteresis Curves B(H)

Figure 3 shows the hysteresis cycle measured for different frequencies. The area on the hysteresis cycle is proportional to magnetic power losses. The hysteresis cycle is wider and consequently the power losses are higher when the magnetization frequencies go up.

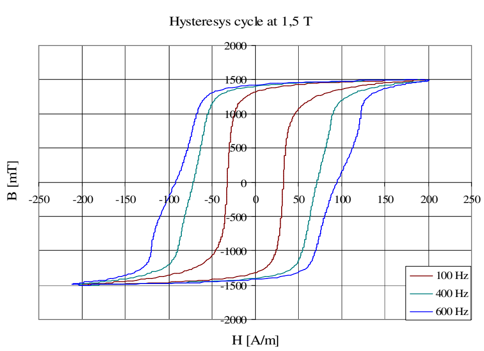

Fig. 3. *Hysteresis cycles for TI at different frequencies (100 Hz…600 Hz)*

Specific magnetic losses in soft magnetic materials, divided into three components: hysteresis, classical eddy current and anomalous losses [2], can be distinguished by considering the dependence of these three loss components on the frequency, flux density, size and shape of the sample, and possibly other factors.

4.4. The Magnetic Power Losses Dependence on Frequency

Figure 4 show the overall magnetic losses dependence $p(B)$ for $f = const.$ for TI, sheet samples at frequency f = 400 Hz.

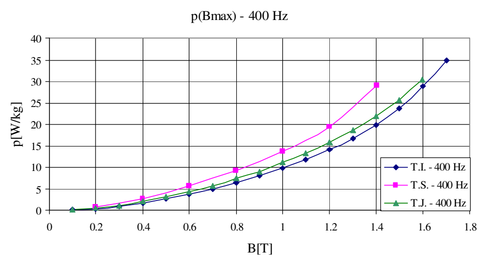

Fig. 4. *Dependence of the magnetic losses $p(B_{max})$ on the magnetic induction for the sheets TS and TJ at f = 400 Hz*

4.5. Estimation of Power Losses Using LabVIEW Programming

Using the experimental results and bilinear interpolation method a LabVIEW program for total losses estimation was made.

The experimental data can be extracted from MPG program as Excel results and converted in text which can be introduced in LabVIEW program. These data have been manipulated in order to create a mesh of total losses depending on magnetic induction and frequency $Ps(B, f)$ as shown in Figure 5.

The LabVIEW program has in its library a virtual instrument (VI) called ***interpolate 2D.vi*** which can make extrapolation or interpolation using several methods. These methods can be chosen manually and for our purpose we chose bilinear interpolation. We use for these interpolation the mesh realized before.

Finally if it is desired to know power losses for a special frequency and induction it is necessary to insert these data

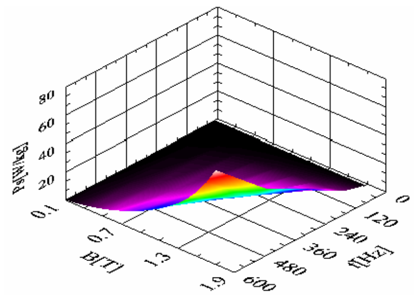

Fig. 5. *3D mesh of total looses depending on magnetic induction and frequency Ps*(B, f)

as input to interpolate 2D.vi and the result will be the power losses for specified frequency and magnetic induction. The program calculates total power losses for all the range of magnetic induction for specified frequency and extracts the value corresponding to desired magnetic induction. The results are shown in Figure 6.

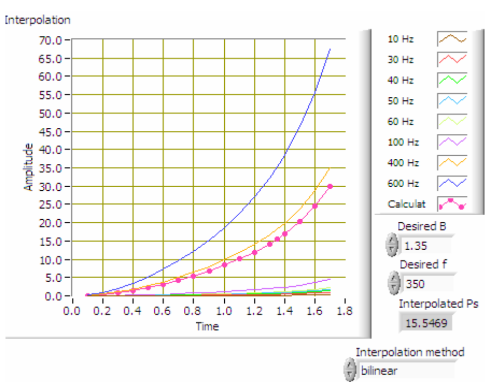

Fig. 6. *The interpolation results for desired B and f*

5. Conclusions

Electrical steel sheets of soft magnetic materials are used in various types of magnetic cores such as transformers, motors and generators. In the cores where the field is unidirectional (transformers and other magnetic device) is a good possibility to use grain oriented silicon steel sheets which offer an easy magnetization direction in the plane of the sheet and thus a great rise of permeability ($\mu_r > 20\,000$ for $f < 100$ Hz) compared to non oriented sheets ($\mu_r \approx 5000$).

The magnetic properties of FeSi sheets are mainly related to the Si content. This is one way to obtain a new material having in mind that an alloy with large content of Si can be used at higher frequencies and will have lower power losses. Actually the research is focused on how to made FeSi alloys by 6% Si using several methods of laser or chemical vapor deposition [3].

The LabVIEW program for interpolation offers a tool for manufacturers to predict what happened with power losses with the rise of frequency and magnetic induction taking into accounts the previous measurements for other frequencies and magnetic inductions.

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