Magnetic properties of amorphous materials used as corps of electric machines

Abstract. In the paper the various methods of determining of the magnetization and losses density characteristics as a function of a flux density of the amorphous steel METGLAS Alloy 2605SA1, are presented in a wide range of frequencies. These characteristics will be used in the design calculations of the high-speed induction motors.

Streszczenie. W artykule przedstawiono charakterystyki magnesowania i stratności w funkcji indukcji magnetycznej i częstotliwości blachy amorficznej Alloy 2605SA1 firmy METGLAS, wyznaczone dla próbek pierścieniowych wykonanych z użyciem różnej technologii oraz dla powszechnie stosowanej w pomiarach przy użyciu aparatu Epsteina prótki ramowej. Omówiono możliwości aproksymacji otrzymanych charakterystyk zależnościami analitycznymi w celu wykorzystania pomierzonych wartości w obliczeniach strat w rdzeniu silnika indukcyjnego. (Właściwości magnetyczne materiałów amorficznych używanych do produkcji maszyn elektrycznych)

Keywords: the magnetization and losses density characteristics, measurement methods, amorphous material
Słowa kluczowe: charakterystyki magnesowania i stratności, metody pomiarowe, materiały amorficzne

Introduction

Magnetic materials currently play major role in many fields of science and technology. They are used for the construction of magnetic circuits in many electric devices such as electric machines, chokes and transformers. The soft magnetic materials find particular application. They can be characterized among other things by narrow hysteresis loop. They are used in magnetic cores of electric machines and transformers [4]. The materials applied in the construction of magnetic cores should be characterized by:

- large saturation induction
- narrow hysteresis loop
- large resistivitiy
- high relative permeability
- low coercive force
- low value of loss.

While designing magnetic cores in the electric machines one needs frequency-varying characteristics of magnetization and specific core losses.

Amorphous steel characteristics measurements

In order to get magnetic properties of amorphous material Alloy 2605SA1 made by METGLAS (thickness 0,0254mm), which was used in magnetic core designing of high-speed induction motors, the research towards determining magnetization and specific core losses characteristics were conducted. The studies were made for 50 ÷ 350 Hz frequency range at the highest possible values of magnetic flux density [7]. During amorphous materials specimen tests the problem of choosing measurement methods and sample type arises. Making a decision is difficult due to the lack of proper regulations and standards in this field. The authors took into consideration that results of measurements would be applied in designing magnetic cores of induction motors. Therefore, the chosen kind of samples corresponds to the structure which is similar to a magnetic circuit of an electric machine.

In order to determine the influence of given sample type on the magnetization and specific core losses characteristics two ring-shaped and one frame-shaped (to Epstein apparatus) samples were taken. The ring-shaped samples used for measurements do not allow determining so-called material characteristics. The obtained results formulate circuit characteristics.

The measurements were carried out using the ring-shaped samples. The first one was made of discs that were cut from amorphous material using spark erosion. The second one was rolled using shears-cut amorphous strip. The dimensions of ring-shaped samples (made of discs) were as follows: outer diameter 120mm, inner diameter 90mm, sheet pack thickness 10,1 mm, mass m=325 g.

Fig.1. The package consists of amorphous material rings.
After covering the ring-shaped samples with isolation, two windings were made – magnetizing and measuring one. The first one was made using several or tens of coils of the thin wire and was placed closest to the core. The winding should cover minimum possible flux, which leaves ferromagnetic core. Yet the induced electromotive force should not exceed measuring capacity of devices.

The magnetizing winding was wound by using the thick wire on the top, with one coil close to the other using one or more layers.

For the ring-shaped sample made of discs the magnetizing winding consisted of \( z_1 = 126 \) turns and the measuring one of \( z_2 = 7 \) turns.

The ring-shaped sample made of amorphous strip had outer diameter 86mm, inner diameter 70mm, height 10 mm, mass \( m_2 = 128 \) g. The magnetizing winding consisted of 87 turns and the measuring winding had 12 turns times two. Moreover, the frame sample weighting 844,1 g was also examined. It was made of 576 strips with dimensions 30x280mm adapted for Epstein apparatus. All the three samples were not submitted to stress relief annealing. The magnetic properties research of the frame sample were carried out in accordance with PN-EN-60404-2 standard [6]. The scheme of measuring circuit was presented in the Fig.3.

The significant part of measuring system is electronic generator – the source of power supply. It enables the voltage and frequency control of the given signal. The measurements of power, magnetizing current, voltage and frequency were carried out with the assistance of Norma 4000 analyser (FLUKE Corp.) [3].

The results of measurements

The results of magnetization characteristics measurements for the ring-shaped sample made of discs, for roll ring-shaped sample and for frame sample in the Epstein apparatus are depicted in Fig. 4. They were evaluated for 50 up to 350 Hz (the characteristics overlap).

As may be observed in the Fig.4 the highest values of magnetic flux density at given value of intensity of the magnetic field are obtained for the frame sample. The worst magnetization characterizes the ring-shaped sample made of discs. Moreover, it was found that the magnetization characteristics do not depend on the frequency of supply voltage. The frequency influences only the width of hysteresis loop.

The obtained results of measurements of the specific core losses characteristics as a function of magnetic flux density for different frequencies, for different samples are presented in the Fig.5-7.
Comparing the measurements of the specific core losses for different kinds of samples one may observe that the highest specific core losses are present for the ring-shaped sample made of discs. The lowest specific core losses values are observed for the frame sample in the Epstein apparatus. It may be explained by the presence of short-circuits between particular discs. They are the effect of the spark erosion cutting that may cause corrosion. The roll ring-shaped sample was not processed. It results in lower values of specific core losses comparing to the sample which was made of discs. The higher values of specific core losses measured for the roll sample (than in the Epstein apparatus) may have their origin in stresses observed during the rolling the strips in the disc. The characteristics obtained from Epstein apparatus are the ones, which match the catalogue data most.

The specific core losses characteristics for two ring-shaped samples as a function of frequency (in the range up to 2000 Hz) for the different magnetic flux density values are presented in Fig. 8-10.

![Fig.8 Specific core losses characteristics as a function of frequency of the ring-shaped sample made of discs for a different magnetic flux density values.](image1)

![Fig.9 The measured specific core losses characteristic as a function of frequency and magnetic flux density of the ring-shaped sample made of discs [1].](image2)

The comparison of the measured specific core losses characteristics as a function of frequency and magnetic flux density for different samples for values of frequency 50 Hz and 300 Hz are presented in Fig. 11-12.

![Fig.10 Specific core losses characteristics as a function of frequency of the rolled ring-shaped sample for a different magnetic flux density values.](image3)

![Fig.11 Specific core losses characteristics as a function of magnetic flux density for different samples for value of frequency 50 Hz.](image4)

![Fig.12 Specific core losses characteristics as a function of magnetic flux density for different samples for value of frequency 300 Hz.](image5)

These characteristics allow to introduce the analytical relationships describing the specific core losses for the given material: \( p = F(B) f = \text{const} \) and \( p = F(f) B = \text{const} \). The most accurate results can be obtained using 3rd order polynomial approximation of these characteristics (as a function of magnetic flux density and frequency).

In order to determine the specific core loss value of the material for desired value of magnetic flux density and frequency (in the range from 20 to 200 Hz) one can use specific core loss characteristics \( p = F(B)_{50Hz} \). It was obtained for the ring-shaped sample made of discs and it can be approximated to the different values of frequency in accordance with:

\[
 p_{Bf} = p_{B50} \left( \frac{f}{50} \right)^{1.26}
\]

(1)
The measured and approximated specific core losses characteristics as a function of frequency (for different values of magnetic flux density) for ring-shaped sample made of discs are presented in Fig. 13.

Fig. 13. Measured (solid line) and approximated (dashed line) specific core losses as a function frequency for different magnetic flux density of the ring-shaped sample made of discs.

In case of the rolled ring sample the approximated relationship is as follows:

\[ \rho_{B_f} = \rho_{B_0} \left( \frac{f}{50} \right)^{1.17} \]

The measured and approximated relationships (2) of specific core losses characteristics as a function of frequency for the rolled ring-shaped sample (for the different magnetic flux density) are plotted in Fig. 14.

Fig. 14. Measured (solid line) and approximated (dashed line) specific core losses as a function frequency for different magnetic flux density of the rolled ring-shaped sample.

As may be observed in the presented plots the introduced analytical relationships are consistent with the measured values up to 200 Hz frequency. For the higher frequencies, the exponent rises due to the growth of eddy-current loss.

Conclusions

Analysing the magnetization and specific core losses characteristics it can be concluded that these characteristics depend on the type of samples chosen for laboratory tests.

On the results also have a significant influence the technology of production the ring and framework samples. Wrong positioning belts of the material creates air gaps, but too tightly too tight winded of coil induce stress in the sample material, which also gives the change of magnetic characteristics of the sample. The exponent in the introduced analytical relationships which approximate the measurement results (up to 200 Hz) concerns the given amorphous material. This exponent also depends on how to do of ring-shape sample. Therefore, in the total loss analysis in magnetic cores the best solution is to use the specific core losses characteristics measured for appropriate magnetic flux density and frequency value and approximated with 3rd order polynomial.

The results most similar to the catalogue data are obtained by testing frame samples in the Epstein apparatus. However, it should be assumed that the characteristics obtained for ring-shaped samples made of discs are the most similar to the characteristics of an induction machine magnetic circuit.

This work was supported by the Polish Ministry of Science and Higher Education under Grant N510 382335.

REFERENCES

[6] PN-EN-60404-2 „Metody pomiaru właściwości magnetycznych stalowych blach i taśm elektrotechnicznych przy użyciu aparatu Epsteina”.
[7] PN-EN 60404-8:2006 Materiały magnetyczne – Część 6: Metody pomiaru właściwości magnetycznych materiałów magnetycznych w przenośności pionowej i poziomej przy częstotliwościach w zakresie od 20Hz do 200kHz z użyciem próbek pierścieniowych.

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