Proceedings of "Applications of Physics in Mechanical and Material Engineering" (APMME 2024)

Share of Additional Losses in Total Core Losses in the Remagnetization Process of Amorphous FeB-Based Alloys

B. Jeż[a,*], S. Stambuła[b], O. Kukuła[b], J.J. Wysłocki[b], N.R.A. Razak[c], L.R. Manea[d] and M. Nabiałek[b]

[a] *Department of Technology and Automation, Faculty of Mechanical Engineering and Computer Science, Czestochowa University of Technology, al. Armii Krajowej 19c, 42-200 Częstochowa, Poland*
[b] *Department of Physics, Faculty of Production Engineering and Materials Technology, Czestochowa University of Technology, al. Armii Krajowej 19, 42-200 Częstochowa, Poland*
[c] *Center of Excellence Geopolymer and Green Technology, Universiti Malaysia Perlis, Taman Muhibbah, 02600 Arau, Perlis, Malaysia*
[d] *Faculty of Industrial Design & Business Management, "Gheorghe Asachi" Technical University of Iasi, 29 D. Mangeron Blv., 70005 Iasi, Romania*

Doi: 10.12693/APhysPolA.147.159 *e-mail: barlomiej.jez@pcz.pl

In the process of remagnetization of magnetic materials at certain frequencies, there are losses that reduce their energy expenditure, which are referred to as total losses. These losses include hysteresis loop losses, eddy current losses, and additional losses. The factor of additional losses is very often overlooked. Its contribution to total losses is considered to be marginal. Even in the case of materials showing the minimization of total losses, such as amorphous materials, this loss factor is important and should not be neglected when studying this phenomenon. The paper presents the results of tests on remagnetization losses of a ferromagnetic amorphous alloy at frequencies from 50 to 1000 Hz. The share of additional losses was separated, and their total contribution to total core losses was determined as a percentage.

topics: bulk amorphous alloys, core losses, additional losses

1. Introduction

Amorphous alloys have different mechanical and magnetic properties depending on their chemical composition. Due to their unique properties, they are often used in many industries. In particular, materials that exhibit specific magnetic properties (both soft and hard magnetic properties) are highly desirable [1–4]. Due to the continuous development of new technologies in the field of electronics and electrical engineering, materials exhibiting such properties, i.e., materials with an amorphous structure, are of particular interest. Therefore, continuous research is being conducted on the design and production of new amorphous and nanocrystalline alloys with new chemical compositions [5–9]. The most characteristic property of magnetic materials is the nonlinear and ambiguous dependence of the magnetic field induction on the intensity of the external magnetic field. When magnetization takes place in a closed circuit, the magnetization curve shows hysteresis. This is caused by energy losses occurring during irreversible magnetization processes (irreversible shifting of domain walls and irreversible rotations of magnetization vectors) [10]. The measure of such losses is the surface area of the hysteresis loop. The shape and size of the hysteresis loop depend on many factors, which are divided into two groups, namely dependent on the properties of the material and the manufacturing technology and dependent on the magnetization conditions. In the first case, the manufacturing technology and the type of material from which the alloy was made determine the magnetic properties. Soft magnetic materials are characterized by a narrow magnetic hysteresis loop, while for hard magnetic materials, it is very wide.

For amorphous alloys with soft magnetic properties, the main parameter determining the application capacity of the alloy is the remagnetization losses. For amorphous alloys, three loss components are distinguished: those related to the surface area of the magnetic hysteresis loop, those related to eddy currents, and the so-called additional losses.

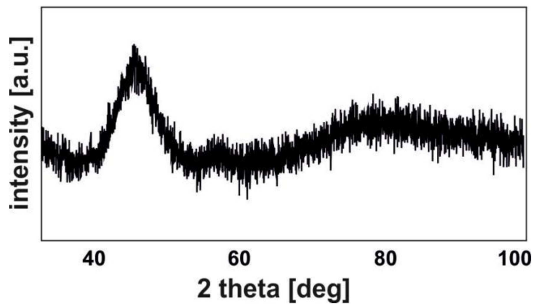

Fig. 1. X-ray diffraction patterns for the samples of the $Fe_{70}Y_5Nb_5B_{20}$ alloy.

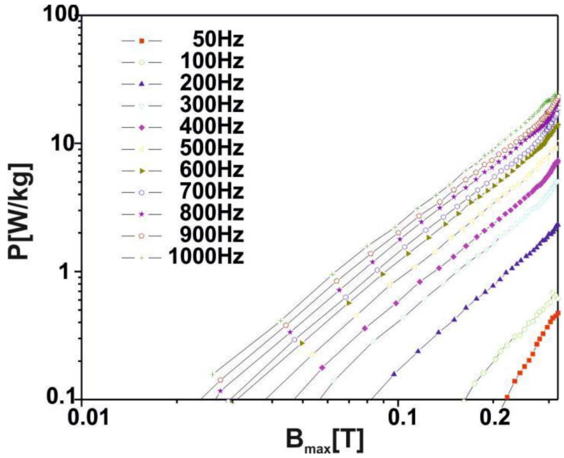

Fig. 2. Core losses for the samples of the $Fe_{70}Y_5Nb_5B_{20}$ alloy.

The study investigated the phenomenon of additional losses in the process of remagnetization of an amorphous alloy with soft magnetic properties. The aim of the work is to demonstrate the significant influence of additional losses on the total remagnetization losses.

2. Experimental procedure

The charge for the production of fast-cooling alloys was produced in an arc furnace. A 10 g ingot was melted from components with a purity of 99.9%. The elements were weighed to the nearest 0.0001 g. Polycrystalline alloys were produced in an arc furnace in a cavity on a water-cooled copper plate. The melting process was carried out in an argon protective atmosphere using a tungsten electrode with a current intensity of 180–300 A. The ingot was melted 5 times, each time turning it over to the other side in order to mix the components. This process was preceded by melting a titanium getter to capture the remaining oxygen in the working chamber. Bulk rapid-cooled alloys were produced using the extrusion method at a rapid cooling speed

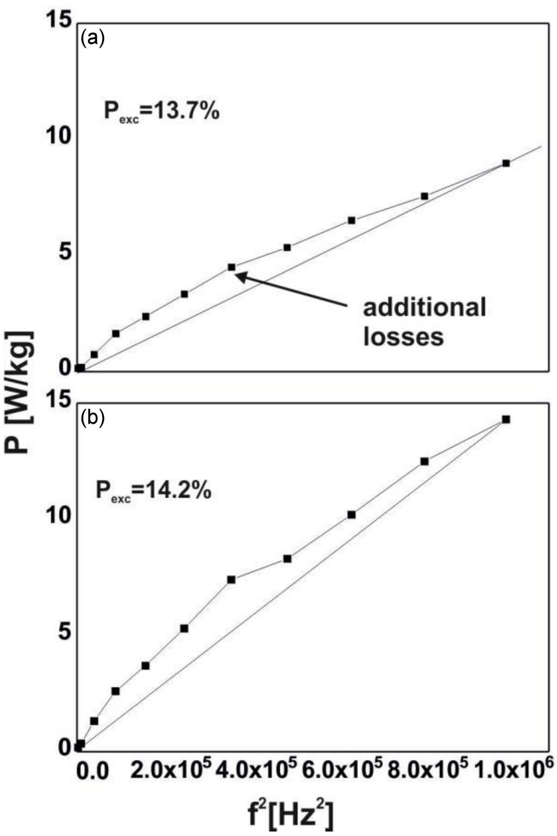

Fig. 3. Additional losses for the samples of the $Fe_{70}Y_5Nb_5B_{20}$ alloy: (a) for $B_{\max} = 0.2$ T, (b) for $B_{\max} = 0.25$ T.

of 10^3 K/s. The process was carried out in an argon protective atmosphere. The charge was placed in a quartz crucible in a 1 mm diameter hole, and the melting itself was carried out using eddy currents. The liquid alloy was pressed into a copper mold under argon pressure. Samples were obtained in the form of 0.5 mm diameter rods. The structure of the obtained alloys was examined using X-ray diffraction. A Bruker D8 ADVANCE X-ray diffractometer was used. Measurements were taken in the range of 30–100° of the 2θ angle, with a measurement step of 0.02° and an exposure time of 7 s per step. Losses due to remagnetization were measured with a ferrometer using the transformer method. Measurements were taken at room temperature in the magnetizing field frequency range of 50–1000 Hz.

3. Results

Figure 1 shows the X-ray diffraction pattern measured for the $Fe_{70}Y_5Nb_5B_{20}$ alloy sample. The shape of the diffraction pattern is typical for alloys with an amorphous structure. Only a broad maximum is visible in the range of 40–55° of the 2θ angle, indicating the lack of long-range atom order.

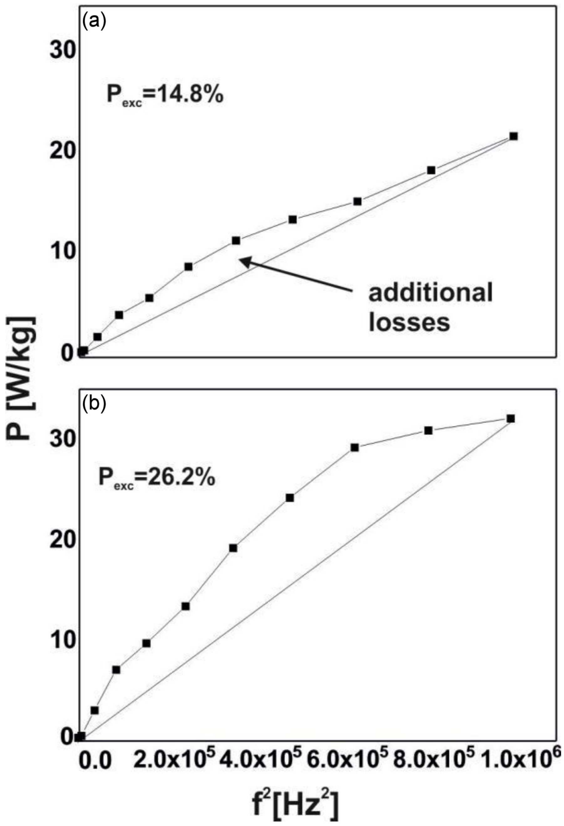

Fig. 4. Additional losses for the samples of the $Fe_{70}Y_5Nb_5B_{20}$ alloy: (a) for $B_{max} = 0.3$ T, (b) for $B_{max} = 0.35$ T.

Figure 2 shows a graph of the dependence of losses on the value of the maximum induction. The losses due to remagnetization increase with the square of the magnetizing field frequency. The measured values are typical for amorphous materials exhibiting soft magnetic properties. The loss values are comparable to those for commonly used Fe–Si sheets [11]. An analysis of losses was carried out depending on the value of the maximum induction. The results of the analysis are presented in Figs. 3 and 4. Amorphous alloys are characterized by significantly weaker electrical conductivity compared to crystalline materials. This limits the formation of eddy currents. For this reason, the main factor generating losses due to remagnetization is the area of the magnetic hysteresis loop. However, as can be seen in Figs. 3 and 4, losses due to remagnetization are not a linear function of the square of the magnetizing field frequency. This difference generates additional losses. The reason for their occurrence is magnetic delays and fluctuations of the chemical composition [10]. As it results from the conducted studies, these factors significantly affect the magnetization process and magnetic properties of alloys with amorphous structure.

4. Conclusions

Losses due to remagnetization are one of the most important operating parameters in the case of materials with soft magnetic properties. Despite many studies, the phenomenon of the so-called additional losses has not been fully explained. In this work, the share of additional losses was investigated depending on the value of the maximum induction for a selected alloy with an amorphous structure. It was shown that additional losses are a significant component of the total losses and range from 13.7% to 26.2%. There is a visible relationship between the value of the maximum induction and the share of additional losses. The obtained results indicate the need for further research, especially in the aspect of changes in the chemical composition and structure relaxation — it should be assumed that a properly designed structure relaxation process should reduce the occurrence of the phenomenon of additional losses without increasing the value of total losses.

References

[1] B. Jeż, *Arch. Metall. Mater.* **69**, 231 (2024).

[2] Y. Han, J. Ding, F.L. Kong, A. Inoue, S.L. Zhu, Z. Wang, E. Shalaan, F. Al-Marzouki, *J. Alloys Compd.* **691**, 364 (2017).

[3] W. Maziarz, A. Kolano-Burian, M. Kowalczyk, P. Błyskun, R. Chulist, P. Czaja, M. Szlezynger, A. Wójcik, *Arch. Metall. Mater.* **68**, 1165 (2023).

[4] S. Park, S.-W. Nam, J.-Y. Cho, S.-H. Lee, S.-K. Hyun, T.-S. Kim, *Arch. Metall. Mater.* **65**, 1281 (2020).

[5] H.F. Li, Y.F. Zheng, *Acta Biomater.* **36**, 1 (2016).

[6] P. Czaja, *Arch. Metall. Mater.* **68**, 1121 (2023).

[7] Y. Ge, Z. Chang, W. Wang, Q. Hou, *Arch. Metall. Mater.* **68**, 31 (2023).

[8] L. Xue, H. Liu, L. Dou, W. Yang, C. Chang, A. Inoue, X. Wang, R.-W. Li, B. Shen, *Mater. Design* **56**, 227 (2014).

[9] Y. Han, Z. Wang, Y. Xu, Z. Xie, L. Li, *J. Non-Cryst. Solids* **442**, 29 (2016).

[10] I. Ibarrondo, J. Degauque, *Vacuum* **53**, 75 (1999).

[11] E. Barbisio, F. Fiorillo, C. Ragusa, *IEEE Trans. Magn.* **40**, 1810 (2004).