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TOTAL LOSS CORES IN THE ASPECT OF MONUMENTS PROTECTION

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Abstract

The achievements of material engineering are used in all areas of life, including the protection of monuments. This applies to both building and construction materials as well as functional materials. Structures of old, historic buildings and exhibits are sensitive to excess heat and mechanical waves. Therefore, methods of limiting the negative impact of these factors on historic buildings are sought. One of the examples of devices that have a negative impact on the environment are transformers. Due to the phenomenon of magnetostriction, these devices emit heat and mechanical waves. For this reason, materials are sought to limit the negative impact of these factors on historic buildings. The study investigated the effect of the addition of Nb at the expense of Mo on the improvement of magnetic properties of the rapid quenched alloy on the Fe-B matrix. Microstructure tests performed with the use of X-ray diffractometer and Mössbauer spectroscopy did not show any changes in the microstructure of the alloy. However, a 1% change in the chemical composition resulted in the rebuilding of the magnetic structure of the tested alloys. The Nb addition increased the value of magnetic permeability, decreased the level of core losses and decreased the share of additional losses. Due to good soft magnetic properties and practically zero magnetostriction, the tested alloys can be successfully used to build transformer cores operating in historic buildings and near exhibits.

Keywords*: X-ray diffraction, Low-frequency mechanical waves core losses, Additional losses,*

Introduction

The protection of historical and cultural heritage is an extremely topical. There are known natural factors influencing the safety of historic buildings, such as: erosion, earthquakes or aeration. In addition to natural factors, there are also factors related to human activity, such as damage as a result of renovation and construction works, environmental pollution, vandalism or excessive exploitation (tourism). These factors have been known for years and their impact on historic buildings is limited as much as possible. Various actions are taken to eliminate technological hazards. These are, for example: reduction of vibrations by making parking spaces more remote, protection of structures against weather conditions, continuous firefighting or physical protection (various types of protection). However, there are other dangers as well, which are largely overlooked today. These include heat, noise, vibration, and other violations of a physical nature. An example of a source of these factors are electrical installations, ubiquitous today. They can be found both in modern buildings and in historic ones, made in a completely different construction technology. Such buildings are not necessarily designed to transmit various types of vibrations, including those from electrical installations such as transformers.

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The operation of these devices is related to the emission of noise, heat and vibrations. These factors, in most cases, are of no significant importance. However, in the case of historic buildings or museum buildings, these factors may have a negative impact on the construction of the structure or the condition of museum facilities. Problems related to excess heat or suppression of mechanical waves can be solved in many ways, including those described in the works [1, 2]. The main source of noise in a transformer is its core. There are also additional noise sources, such as the coil winding. The effect of vibrations coming from the operation of electrical devices is possible to be limited by using modern soft magnetic materials for the construction of transformer cores, such as amorphous alloys. Due to zero magnetostriction and low core losses, these materials can be used to build transformer cores limiting the emission of undesirable vibrations.

Amorphous alloys have been known for several decades. They are usually produced in the form of thin ribbons characterized by excellent magnetic properties, a low value of the coercive field and a high value of saturation magnetization [3-5]. The disadvantage of these materials limiting their application possibilities is the maximum thickness of the ribbons not exceeding several dozen µm. A relatively new group of materials are the so-called bulk amorphous alloys [6-10]. Fe-based alloys is an interesting group among these materials. These alloys are characterized by good magnetic properties, comparable to ribbons of the same chemical composition [11-15].

The most important parameter determining the efficiency of transformers is the core losses. They can be determined by the following equation:

$$P_t = P_{his} + P_{cl} + P_{exc} \qquad (1)$$

where: P_{his} - hysteresis losses; P_{cl} - eddy current losses; P_{exc} - additional losses.

During the magnetization process, due to the conductive properties of amorphous alloys, eddy currents occur. The eddy currents create a field opposite to the applied magnetic field, causing losses. The key loss component is this related to the surface of the dynamic magnetic hysteresis loop. The occurrence of hysteresis is related to irreversible remagnetization processes, which in turn are the result of the presence of centers that inhibit the movement of the domain walls. These two components are well described in the literature. The third component is less well described and is often overlooked in transformer calculations and design. The so-called additional losses related to migration relaxation and the so-called fluctuating viscosity can be approximated by the relationship [16]:

$$P_{exc} = 8{,}76\sqrt{\sigma G S V_0}\, B_{peak}^{3/2} f^{3/2} \qquad (2)$$

where: G - Dimensionless factor; S - Cross-section of the sample; V_0 - Constant associated with the impact of inhibitory centres on domain walls; σ - Electrical conductivity; f - Frequency; B_{peak} - Maximum induction value.

Appropriate selection of the production technique and optimization of the chemical composition and possible thermal treatment of alloys may reduce the level of losses and thus reduce the impact of undesirable vibrations on building structures or exhibits.

The article presents the results of research on the structure and losses for remagnetization of bulk amorphous alloys $Fe_{70}Y_5Nb_2Mo_3B_{20}$ and $Fe_{70}Y_5Nb_3Mo_2B_{20}$. The alloys were made using the rapid quenched method: injection casting. The aim of the research was to determine the effect of the addition of Nb at the expense of Mo on the structure and magnetic properties of bulk amorphous alloys based on Fe-B, in particular on the level of additional losses.

Experimental

Ingots of $Fe_{70}Y_5Nb_2Mo_3B_{20}$ and $Fe_{70}Y_5Nb_3Mo_2B_{20}$ alloys were produced in an arc furnace under an argon protective atmosphere. Components with a purity above 99.95% were used. The melting process was carried out using a non-fusible tungsten electrode on a water-cooled copper plate. A working current in the range of 180 - 280A was used. In order to obtain a clean atmosphere, the working chamber was pumped using a set of two pumps, rotary and diffusion. Additionally, the working chamber was flushed with argon and pumped out again. The charge was smelted 5 times each time by turning the ingot over using a manipulator. 10-gram ingots were produced, then mechanically cleaned, divided into smaller pieces and subjected to ultrasonic cleaning. Rapid quenched alloys were produced by the injection casting method [17, 18]. The production process was carried out in the same conditions as during the production of ingots. The polycrystalline charge was placed in a quartz crucible in such a way that the alloy was at the height of the copper coil. The charge was melted using eddy currents. The liquid melt was forced into the copper mold under argon pressure through a hole in the quartz crucible. The alloy was obtained in the form of rods 0.5mm in diameter and 10mm long.

The structure of the alloys was studied using X-ray diffraction. The BRUKER Model Advanced 8 diffractometer was used, equipped with a CuKα lamp. The tests were carried out in the range of 30-100° two theta angle with an irradiation time of 5 seconds per measurement step of 0.02°.

The Mössbauer transmission spectra for the tested samples were measured using the POLON Mössbauer spectrometer (^{57}Co 100mCi source). Spectral analysis was performed using the NORMOS [19] software and the hyperfine field induction was made. In order to determine the distribution of hyperfine fields on ^{57}Fe nuclei, according to the Hesse-Rübatsch method [20], each experimental spectrum was presented as the sum of elementary sextets:

$$T(v) = \int_0^\infty P(B) L_6(B, v) dB \qquad (12)$$

where: P(B) - hyperfine magnetic field induction distribution; L_6 (B, v) - elementary Zeeman sextet; v - relative speed of the source relative to the absorbent.

The mean value of induction Bhf was determined. Due to the asymmetry of the Mössbauer spectra, a linear relationship between the isomer shift (IS) and the hyperfine field induction (B_{hf}) was assumed during the fitting process [19].

$$IS(B_{hf}) = IS(B^0_{hf}) - \alpha(B_{hf} - B^0_{hf}) \qquad (13)$$

where: B^0_{hf} = minimum hyperfine field induction; α = coefficient.

Magnetic permeability and losses as a function of maximum induction were measured using a Ferrometer. The samples of the tested alloys were mounted in yokes made from superpermalloy. The measurements were carried out over the range of 50 - 1000Hz. The measurements were carried out at room temperature. Based on the measurements, additional losses as a function of the square of the frequency were determined.

Results and discussion

Figure 1 shows the X-ray diffraction images for the tested alloys. The diffractograms measured for the tested samples are typical for amorphous materials. Only a broad maximum is seen in the range of 40-50° two theta. This maximum is related to the reflection of X-rays from chaotically arranged atoms in the volume of the alloys. There are no narrow peaks of significant intensity that indicate the presence of crystalline phases. Figure 2 shows the Mössbauer transmission spectra measured for the tested alloys.

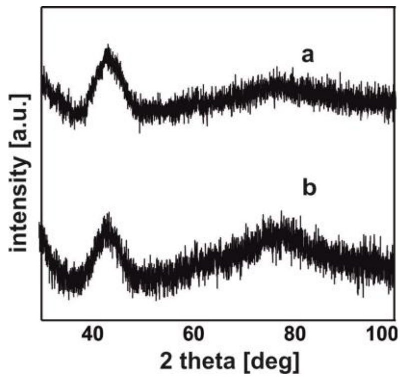

Fig. 1. X-ray diffractograms for the tested alloys:
a) $Fe_{70}Y_5Nb_2Mo_3B_{20}$, b) $Fe_{70}Y_5Nb_3Mo_2B_{20}$

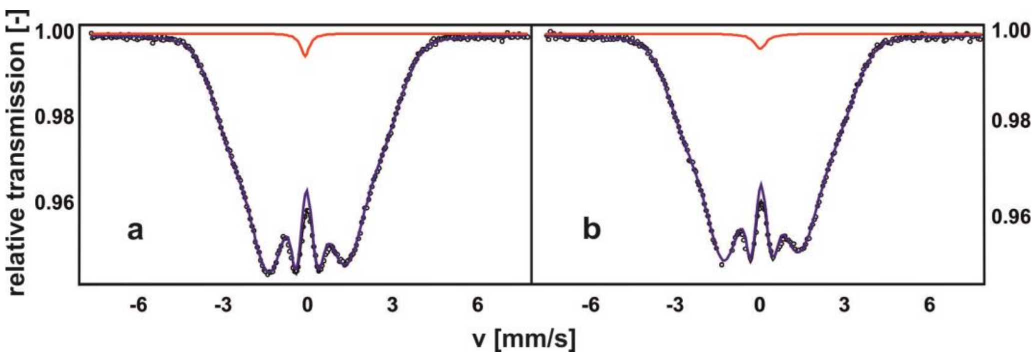

Fig. 2. Transmission Mössbauer spectra measured for the samples of the tested alloys:
a) $Fe_{70}Y_5Nb_2Mo_3B_{20}$, b) $Fe_{70}Y_5Nb_3Mo_2B_{20}$

The samples in the form of a powder were tested. The recorded spectra are typical of amorphous materials showing ferromagnetic properties, which is confirmed by the results of X-ray examinations. Asymmetric spectra consist of overlapping broad lines. The obtained spectra were analyzed using specialized NORMOS software. Based on the analysis, the distribution of hyperfine field induction on ^{57}Fe nuclei was obtained. The distributions are presented in figure 3.

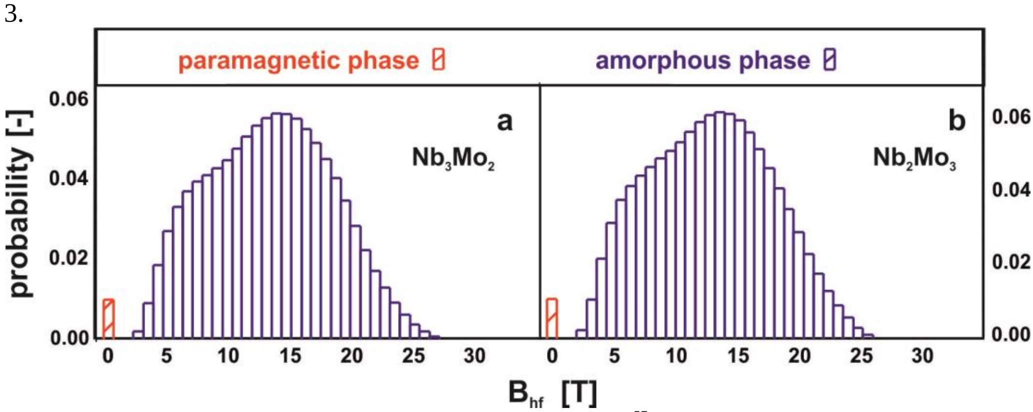

Fig. 3. Distribution of hyperfine field induction on ^{57}Fe nuclei obtained for alloys:
a) $Fe_{70}Y_5Nb_2Mo_3B_{20}$, b) $Fe_{70}Y_5Nb_3Mo_2B_{20}$

The distributions of hyperfine fields for the studied alloys are similar to each other. They have low and high-field components, which proves the presence of areas with different concentrations of Fe atoms in the volume of alloys. This means the existence of different surroundings of Fe atoms and the existence of different distances between ferromagnetic atoms. Moreover, a non-zero value of the oversubstantial field induction at the origin of the coordinate system was recorded for. It is related to the presence of about 1% paramagnetic order in the volume of the tested alloys. It is related to the significant separation of Fe atoms in these regions. Obtaining a fully amorphous structure of alloys is important in terms of monument protection. Amorphous alloys are characterized by practically zero magnetostriction, which allows to reduce the emission of noise and vibrations that may adversely affect the structure of historic objects and works of art. The presence of crystallites may not only deteriorate magnetic properties but also increase the level of magnetostriction. Figure 4 shows the dependence of the magnetic permeability on the amplitude of the magnetizing field.

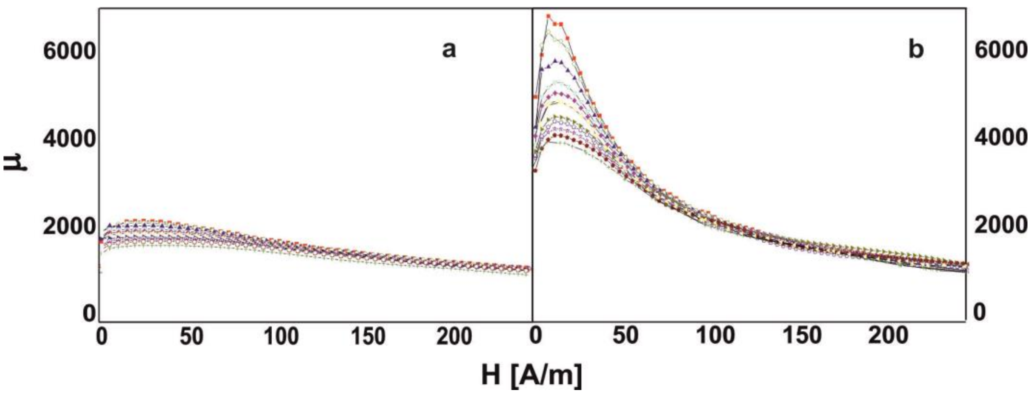

Fig. 4. Magnetic permeability measured for the produced alloys for the frequency 50 - 1000Hz: a) $Fe_{70}Y_5Nb_2Mo_3B_{20}$, b) $Fe_{70}Y_5Nb_3Mo_2B_{20}$

The μ(H) curves show the maximum corresponding to the maximum permeability. In the case of the tested alloys, the maximum magnetic permeability occurs at similar values of the amplitude of the magnetizing field of 10-20A/m. An increase in the amplitude of the magnetizing field causes a decrease in the value of magnetic permeability. Magnetic permeability decreases with increasing frequency of the magnetizing field. The addition of Nb significantly increases the permeability value from about 2,000 to over 6,000. Figure 5 shows the core losses as a function of the maximum induction for the tested alloys.

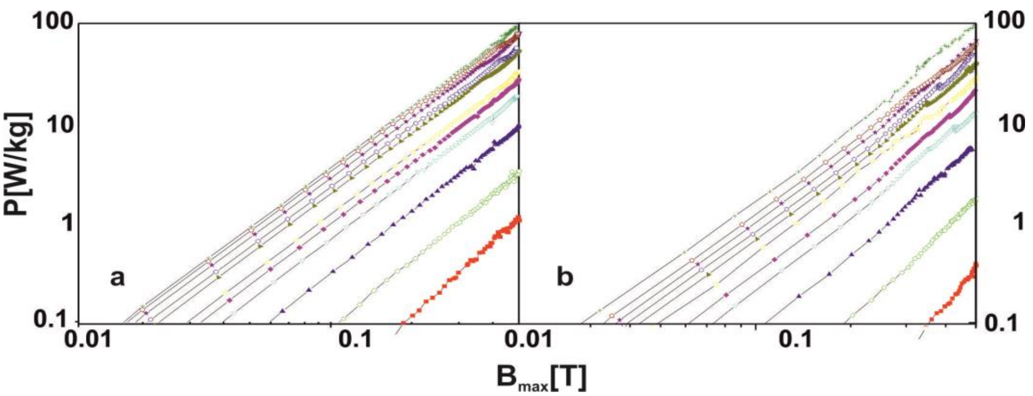

Fig. 5. Magnetization losses as a function of maximum induction for the produced alloys for the magnetizing field frequency of 50 - 1000 Hz: a) $Fe_{70}Y_5Nb_2Mo_3B_{20}$, b) $Fe_{70}Y_5Nb_3Mo_2B_{20}$

Core losses are related to the magnetic hysteresis loop area, eddy currents and additional losses. Compared to classic amorphous alloys, bulk alloys are characterized by a larger cross-sectional area. This generates lower resistance (higher conductivity) and the formation of eddy currents which are a significant component of the core losses. For the tested alloys, the value of core losses was obtained at a lower level as in the case of the commonly used Fe-Si sheets [21]. The low level of losses reduces the emission of vibrations and heat during the operation of a transformer made of this type of material. The value of losses increases with the increase of the frequency of the magnetizing field. Based on the presented results, the analysis of additional losses for the tested alloys was carried out (Fig. 6).

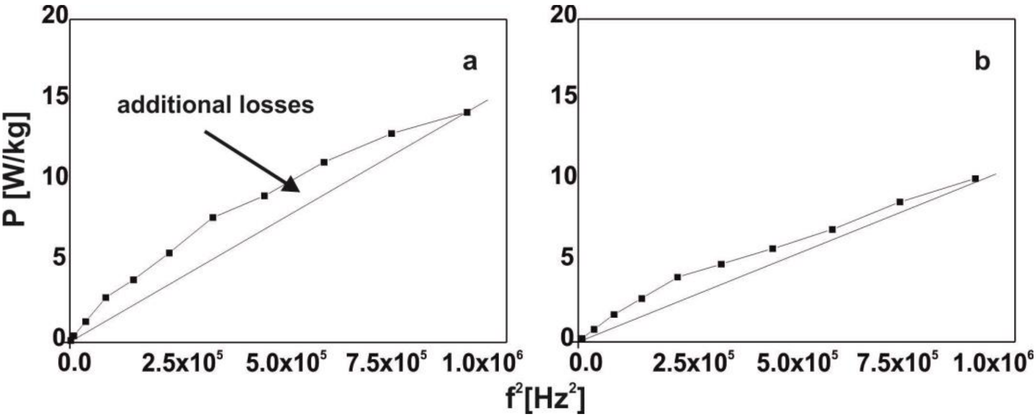

Fig. 6. Core losses as a function of the square of the frequency of the magnetizing field for the alloy: a) $Fe_{70}Y_5Nb_2Mo_3B_{20}$, b) $Fe_{70}Y_5Nb_3Mo_2B_{20}$

The core losses are presented as a function of the square of the frequency of the magnetizing field. Losses increase with the square of the frequency of the magnetizing field. The experimentally determined losses are not a linear function of the square of the frequency. It is a consequence of the occurrence of losses related to composition fluctuations and magnetic delays. The addition of Nb reduces the level of losses and the share of additional losses from 18.6% to 12.4%, which corresponds to a much higher magnetic permeability for the $Fe_{70}Y_5Nb_3Mo_2B_{20}$ alloy.

As is know, maintaining proper air quality is very important for the protection of works of art. Modern ventilation and air conditioning systems are responsible for this in museums. However, these systems are not foolproof. Even a slight change in temperature can influence the growth of fungus. In addition, there may be slight changes in the dimensions of historic objects (their expansion or contraction), as a result of which they may be damaged, for example by cracks in the surface material. In addition, some materials may sweat due to the increase in temperature, which results in additional damage. Mechanical waves can stress or resonate materials. The increase in stress can lead to irreversible damage such as deformation or fractures. Transformer cores constructed of crystalline materials generate continuous vibration and heat. Their intensity seems to be low. However, repetitive stress cycles can lead to slight distortions in the delicate structure of works of art (for example, paint coatings or sculptures) over time. Additionally, vibrations from transformers may accumulate with vibrations from other sources. When the deformation exceeds a certain critical level characteristic of the material, mechanical failure will occur.

The low level of losses and the low share of additional losses significantly reduce the generation of excessive heat and the generation of mechanical waves during the alloy remagnetization process. For this reason, the tested materials can be successfully used to build transformer cores operating in historic buildings and near exhibits.

Conclusions

Bulk amorphous alloys on the Fe-B matrix are characterized by a lower level of losses as in the case of crystalline Fe-Si sheets. In addition, due to the lack of a crystal structure, these materials can be used in the construction of transformers operating at high frequencies. The study showed that a slight change in the chemical composition may significantly improve the magnetic properties of these alloys. The loss mechanism in amorphous alloys is more complicated than for crystalline alloys. This is related to the occurrence of a more complex domain structure and the difficulty of linking the microstructure with the level of losses. In the case of the tested alloys, the structure tests did not show that the 1% addition of Nb at the expense of Mo had an impact on the alloy microstructure. The recorded images of X-ray diffraction and Mössbauer spectroscopy are almost identical. However, the magnetic properties of these alloys are completely different. An alloy with a higher Nb content is characterized by an almost 3 times higher value of magnetic permeability, a much lower level of core losses (decrease from 14.3W/kg to 10.1W/k with a maximum induction value of 0.2T) and a lower share of additional losses (decrease from 18.6% to 12.4%). It should be noted that the addition of Nb influences the ordering of the magnetic structure and facilitates the process of magnetization. Probably the higher content of Nb at the expense of Mo generates a reduction in local fluctuations in the chemical composition, which reduces the level of additional losses.

As shown in the work, bulk amorphous alloys are characterized by good magnetic properties and can be successfully used as materials for the construction of low-loss transformer cores. Moreover, due to their virtually zero magnetostriction, they can be used to reduce noise and vibration wherever additional vibration can cause damage, for example in historic buildings or close to exhibits. In addition, the low level of additional losses may reduce the operating temperature of transformers, which is an additional advantage in the aspect of monument protection.

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