THERMOMAGNETIC MODIFICATION OF PRODUCTS FROM AMORPHOUS OF AN ALLOY

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Introduction

The possibility of improvement of magnetic properties of semiproducts made from soft magnetic material and alloys by means of thermomagnetic treatment (TMT) is a subject matter of a good many of publications [1–4]. However, in the case of end items, the above problem is being solved virtually only on steels [5–7]. Yet, upon mechanically manufacturing finished products from soft magnetic materials their starting magnetic properties are subjected to mechanical actions and undergo essential changes, which results in decreasing performance, say, of measuring current or voltage transformer, and as a consequence, the accuracy rating.

The work presented deals with the possibility of improvement of magnetic properties of finished products of amorphous alloy $Fe_5Co_{70}Si_{15}B_{10}$, whose material has initially been subjected to a standard mode of heat treatment.

Experimental

The pieces under study were products in the form of ring-type transformer magnets made of amorphous alloy $Fe_5Co_{70}Si_{15}B_{10}$. They have the Curie temperature T_c=160 °C, ribbon thickness δ = 0.025 mm, ribbon length, 15 mm. The magnetic cores imbued with glue have a rigid structure without a protecting closure. Their ribbon surface is covered with a film of polymer materials 0.4 to 1.2 mm in thickness. It serves as an insulation layer which stands for a voltage no less than 5kV The magnetic cores are manufactured varying in the unit size with an outer diameter of no more than 40 mm and inner diameter, no less than 10mm; the mean diameter being 26 mm.

The specified products were treated in a dc magnetic field which was aligned with their longitudinal axis and perpendicular to the longitudinal axis of the ribbon proper. The magnetic field strength was changed from 10^3 to 10^4 A/m at T ° varying from 100 to 180 °C and holding time of up to 20 min. The common steps for all the modes of treatment of the products were heating from room temperature with a rate of ~10 °C/min to a corresponding temperature $h<T_c$, holding at the specified temperature for some time under magnetic field, and subsequent cooling with a rate of ~3 °C/min to room temperature.

Determination of magnetic permeability μ_{max}, coercivity (H_c), and specific magnetic losses (P_s) prior and after the thermomagnetic treatments was performed via estimation of the hysteresis loops taken at a frequency f=50Hz at maximal amplitudes of magnetic induction (B_m) 0.01, 0.02, 0.05, 0.1, and 0.2 T.

The measurements of hysteresis loops and processing of the experimental results were performed using a highest-accuracy setup UVT-82-A-93 registed in the State List of Measuring Devices of the Russian Federation. The error of measuring magnetic characteristics did not exceed 5%. In the setup an induction method was employed. Instant voltage values fixed in the course of measurements in the measuring coil of the sample under study and measuring resistor in the magnetizing circuit are transformed by an analog-digital converter in the digital codes which are recorded in the memory of a PC assisting the setup, which is used to calculate magnetic characteristics of the given sample material.

The results of measurements are shown in Table.1. It follows from the data that, depending on the regime of the thermomagnetic treatment at the magnetic induction values (B_m) from 0.01 to 0.2 T, it is possible to diminish the magnetic losses (P_s) by a factor 1.2–1.9, the coercivity (H_c), 1.4–2 and to increase the magnetic permeability as high as 1.5–2 times after heating products to 120–125 °C and holding up to 10 min in a dc magnetic field with a strength H=65–70kA/m. The isolation properties of the coatings are preserved in this range of the TMT temperatures.

Thus, the optimal result of the thermomagnetic treatment of the products in the form of ring transformer magnets made of amorphous alloy GM 501 manifests itself in a narrow temperature range at definite holding times and strengths of the external magnetic field. It depends on the dimensions and shape of the materials and products as well.

Table 1. Results of measurements of the specific magnetic permeability (μ_{max}), coercivity (H_c), magnetic losses (P_s) at the frequency 50 Hz upon magnetization reversal of ring-type transformer magnetic core.

Amplitude of magnetic induction B_m,T	μ_{max} 10^{-3}		$H_c \cdot 10^2$, A/M		$P_s \cdot 10^{-5}$ (W/kg)	
	prior TMT	after TMT	prior TMT	after TMT	prior TMT	after TMT
0,01	**80**	**130**	2	1,2	**0,2**	**0,05**
0,02	110	150	**4**	**2**	1	0,5
0,05	160	210	8	6	8	5
0,1	250	320	16	12	40	20
0,2	340	430	27	21	100	80

Upon a standard heat treatment of the samples, an initial state of the amorphous ribbon is formed when longitudinal, transverse, perpendicular 180° and closure 90° domains are present (Fig. 1). In this case a spontaneous emergence of the longitudinal (1) and transverse (2) 180° domains with alternating polarity is conditioned by the penetration of gaseous bubbles into the space between the surface of contact of the ribbon under production and the formative disk. In this region the resistance of the contacting surface sharply increases and there arises a transverse contraction of the ribbon bulk, and magnetization becomes oriented perpendicular to the ribbon surface.

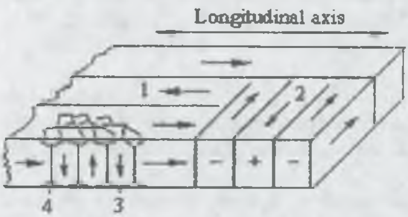

Fig. 1. Fragment of local distribution of the longitudinal (1), transverse (2), perpendicular (3) 180° and closure (4) 90° domains over the amorphous ribbon after the standard heat treatment.
← orientation of magnetization in the domains.

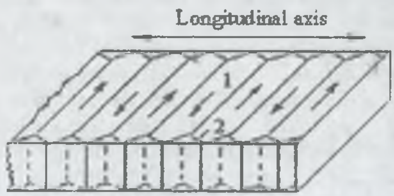

Fig. 2. Fragment of local distribution of the transverse180° (1) and closure 90° domains (2) over the amorphous ribbon after TMT.
← orientation of magnetization in the domains.

In the case of the thermomagnetic treatment of the above products in the longitudinal magnetic field, the improvement of their magnetic properties is related to a significant decrease in the fraction of the 180° magnetic domains, magnetized upon the standard heat treatment perpendicular to the ribbon surface (3), which took almost 30% of the volume.

When the domains magnetized perpendicularly and longitudinally disappear, the magnetic field of TMT gives rise to an anisotropic structure consisting of 180°domains with the magnetization aligned with the applied field (Fig. 2). At the sides of this ribbon there are formed 90° domains which provide the closure of the magnetic flux and decrease of the magnetostatic energy of the ribbon.

In the next stage, upon measuring magnetic characteristics of the products, the magnetizing force field of the transformer coil is directed (just as in the case of application of measuring current transformers) along the ribbon surface, that is, along its long axis (Fig. 1). The 90°closure domains formed upon TMT (Fig. 2) become nuclei of the magnetization reversal in the direction of the applied ac field, which serves to lower its strength and diminish the energy spent on the switching of the ring magnets. Such a decrease is traceable to the fact that the magnetization reversal proceeds by the low-energy mechanism of the domain wall displacement rather than by the energy-taking mechanism of magnetization rotation.

Conclusion

An optimal regime of thermomagnetic treatment of products made of amorphous alloy $Fe_5Co_{70}Si_{15}B_{10}$ in the form of ring-type transformer magnetic core is found which provides a reduction of magnetic losses (P_s) up to by a factor of 1.9, decrease in coercivity (H_c) as large as by a factor of 2, and up to twofold increase in magnetic permeability.

Thus, the studies performed serve to develop new ideas about the possibilities of the thermomagnetic treatment, allow an effective realization of the reserves for the long-term operation of the products made from soft magnetic materials widely employed, say, in the magnetic cores of electrical machines and transformers.

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