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Effectiveness of the magnetostatic shielding by the cylindrical shells

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ABSTRACT

The experimental research of the magnetostatic shielding effectiveness and the analytical calculations of the average magnetic permeability of single-layer cylindrical sample of the shields based on electrolytically deposited $Ni_{80}Fe_{20}$ alloy are carried out. The locations of maxima on the Ef(H) and $\mu(H)$ curves do not match each other, which is difficult to interpret in terms of the shunting model. The results are explained by the non-linear distribution of the magnetic permeability through the thickness of the shield. It has been shown that in the magnetic fields range from 100 A/m up to 2700 A/m, the shields based on the $Ni_{80}Fe_{20}$ alloy are preferred over ones based on the 84KHSR amorphous ribbon. It is concluded that at the selection of shield materials it should take into account not only the main magnetic characteristics – μ; H_s; H_c but also H_{max} parameter, which is important to evaluate the effectiveness of magnetic shielding.

1. Introduction

The most difficult case of protection from external fields effect is the case of the static magnetic fields shielding [1,2]. Usually, at considering the magnetostatic shielding it is based on the principle of shunting the magnetic field by ferromagnetic material [3,4], the main essence of which lies in the closure of the force lines through the material with low resistance to the magnetic flux. The R_m resistance value to the magnetic flux exerted by shield with μ magnetic permeability, an l average length of the magnetic induction lines through the material and S cross-section in a perpendicular direction to the magnetic flux is given by [5]:

$$R_m = l/\mu S \quad (1)$$

From this, it follows that in order to achieve maximum effectiveness of the static magnetic fields shielding it should be used as the materials with maximum values of μ and S.

For the analytical calculations of the shield effectiveness the value of μ is usually assumed to be constant for any point of the magnetic shield [6]. In a real situation, it is based on the boundary conditions for the normal and tangential components of the magnetization and induction vectors [7], the distribution of the magnetic permeability through the material thickness of the shield is more complex and non-linear.

Therefore, in this paper we carried out the experimental and analytical studies of the magnetostatic shielding effectiveness of single-layer cylindrical sample shields in order to develop optimal protection of different device bodies and wide-range of application equipments.

2. Experiment

The magnetic shields are formed by the electrodeposition method of the soft magnetic $Fe_{20}Ni_{80}$ alloys [8]. The copper billets of cylindrical shape with an external diameter of 22 mm, an inner diameter of 20 mm and length of 40 mm were used as the substrates. The thickness of the magnetic layer of the shields was varied in range from 50 μm to 400 μm.

The quantitative evaluation of the Ef shielding effectiveness is based on the measurement results of the magnetic field strength or induction ratio in the protected area of space at the H_{ext} (or B_{ext}) shield absence and at the H_{int} (or B_{int}) shield presence [9]:

$$\mathrm{Ef} = B_{ext}/B_{int} = H_{ext}/H_{int} \quad (2)$$

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Setting for the shield effectiveness research consisted from three mutually perpendicular Helmholtz coils, inducing a three-component permanent magnetic field from 0 up to 4500 A/m [10]. The test sample of shield was placed in a uniform magnetic field created by one of the pairs of coils (magnetizing coils), powered by DC B5-86/1 current source and was monitored using an DC M253 ammeter. To change the direction and type of the current (DC, AC) in the magnetizing coils a switching device is used. The second pair of coils (compensation coils) is used to compensate the Earth's magnetic field. The power of the compensation coils is performed by DC B5-86/1 current source and controlled with the help of DC M253 ammeter. By adjusting the amount of current and the coil axis direction the compensation of the external Earth's magnetic field to at least 5 A/m was provided.

The calculation of shielding effectiveness is based on measurements of the Hall potential in the predetermined central region of area without E_{ext} shield and with E_{int} shield [10]. Hall sensor is placed in the central zone of the test sample that corresponds to center located along the axis of the magnetizing coils. The Hall potential measurements are carried out using a calibrated Hall element with sensitivity of 1 mV/30 Oe and V7-34A digital voltmeter or DC V2-39 nanovoltmeter. The Hall sensor energizing is carried by a B5-44A stabilized DC power supply. To demagnetize the test sample a variable decreasing to zero electromagnetic field with frequency of 50 Hz is used. The alternating electromagnetic field with voltage up to 2000 A/m was produced by the AROS-2 autotransformer and monitored by the C4200 AC voltmeter.

The heterogeneity in the distribution of the magnetic field induction along three axes in both directions relative to the center of three coils at 4 cm; 6 cm; 8 cm and 10 cm is not more than 0.4%; 0.8%; 1.7% and 3.1%, respectively.

The initial magnetization curve, the hysteresis loops, the static magnetic characteristics – the μ_{max} maximum magnetic permeability, the H_c coercive force, the H_s saturation field were measured by ballistic method [11]. For this aim the samples of the annular shape with an outer diameter of 45 mm and an inner diameter of 25 mm were manufactured. The magnetizing coil is formed by Ø0.5 mm wire in amount of 100 turns and the measuring coil is formed by Ø0.08 mm wire in amount of 200 turns. The control of the magnetic characteristics was performed by vibration method [12] using a universal cryogenic high-field measurement system – Liquid Helium Free High Field Measurement System (by Cryogenic Ltd., London, UK) at room temperature.

3. Results and discussions

To interpret the data on the shielding effectiveness the initial magnetization curve and hysteresis loop characteristics for the $Ni_{80}Fe_{20}$ alloy films were experimentally measured. The μ_{max} values for the $Ni_{80}Fe_{20}$ alloy with thicknesses from 20 μm up to 200 are $(0.8–1.3)\times 10^4$ (Fig. 1), the values of H_c and H_s are 40–50 A/m and 350–400 A/m, respectively.

Fig. 2 shows the dependence of the shielding effectiveness versus the external magnetic field strength for samples with thickness of 50 μm, 180 μm and 400 μm. For a better perception of the results for the Ef(H) graphics two scales on the ordinate axis are constructed. Left scale corresponds to the Ef(H) dependence for the samples with thicknesses of 180 μm and 400 μm, right scale corresponds to the Ef(H) dependence for the sample with thickness of 50 μm. As it can be seen, with increasing of thickness of shields based on $Ni_{80}Fe_{20}$ alloy [13] the shielding effectiveness increases, which is consistent with the (1) and (2) shunting principle and associated with an increasing of the cross sectional area of the shield and, accordingly, with decreasing of the magnetic

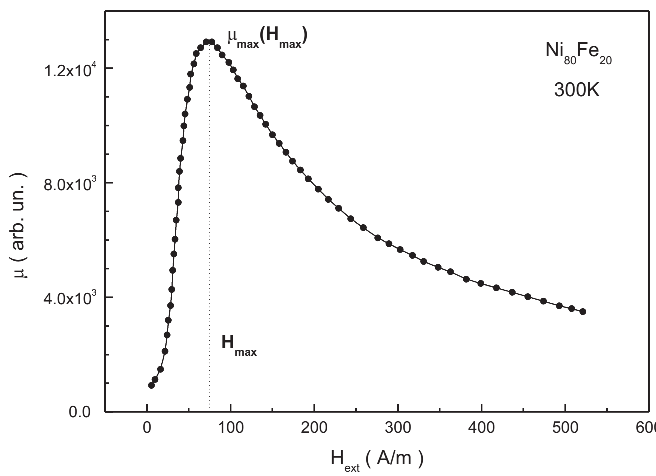

Fig. 1. The initial magnetization curve for the $Ni_{80}Fe_{20}$ alloy film with thickness of 200 μm at 300 K.

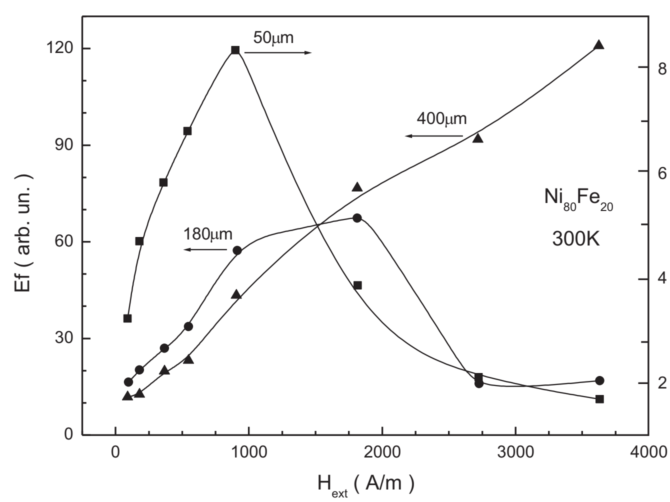

Fig. 2. The shielding effectiveness depending on the strength of external magnetic field for the $Ni_{80}Fe_{20}$ alloy films with thickness of 50 μm (■); 180 μm (●) and 400 μm (▲) at 300 K.

resistance. However, it should be noted that with increasing of the external magnetic field strength for the shields with thicknesses of 50 μm and 180 μm the effectiveness increases to strength values of 900–1000 A/m and 1800–2000 A/m, respectively. At higher values of H_{ext} strength the decline of effectiveness is observed. For the shield with thickness of 400 μm over the entire range of used the external magnetic field strengths up to 3600 A/m the increase of the shielding effectiveness is observed.

The course of Ef(H) dependence for the shield with thickness of 50 μm is similar to the course of $\mu(H)$ dependence (Fig. 1). However, it should be noted that the positions of the $Ef_{max}(H_{max1})$ and $\mu_{max}(H_{max2})$ maxima are achieved at the different values of the $H_{max1}\neq H_{max2}$ argument. At the increasing of the shield thickness up to 180 μm the shielding effectiveness maximum is shifted even further to higher values of the external magnetic field strengths, and for the shield with thickness of 400 μm the maximum of the shielding effectiveness is not achieved over the entire range of used fields. These experimental results are difficult to explain within the shunting model. It is essentially manifested the process nonlinearity.

It is based on the (2) expression and the data shown in Fig. 2, we can estimate the values of the H_{int} magnetic field strengths inside the finite cylindrical shields with thickness of 50 μm; 180 μm and 400 μm (Tables 1–3).