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Study of Magnetic Structure of Permanent Magnets by Mössbauer Spectroscopy

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Abstract

Mössbauer spectroscopy method for determining the relative remanent magnetization of anisotropic permanent magnets is described. The method has been experimentally verified on powder-based permanent magnets made of barium ferrite $BaFe_{12}O_{19}$. The experimental results of the Mössbauer spectroscopy method are coincides with the magnetic measurements.

Keywords

Monodomain Particle, Permanent Magnet, Remanent Magnetization, Saturation Magnetization, Magnetic Anisotropy, Mössbauer Spectroscopy, Zeeman Splitting

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1. Introduction

It is known that monodomain particles appear when strong powdering of ferromagnetic materials takes place. A physical reason of such phenomenon is that with the decrease in particle size the particle magnetostatic energy, which is proportional to the particle volume decreases faster than the domain walls energy, which is proportional to the particle surface area. At some critical size the monodomain state becomes energetically profitable. A critical diameter, at which the particle transforms from a multidomain into monodomain state is determined by the following expression [1]:

$$d_{cr} = \frac{9}{2\pi}\frac{\sigma}{M_S^2} \quad (1)$$

where σ is the domain wall energy and M_S the spontaneous magnetization of the particle.

Magnetic powders consisting of monodomain particles have found a wide technical usage [2], particularly for manufacture the permanent magnets.

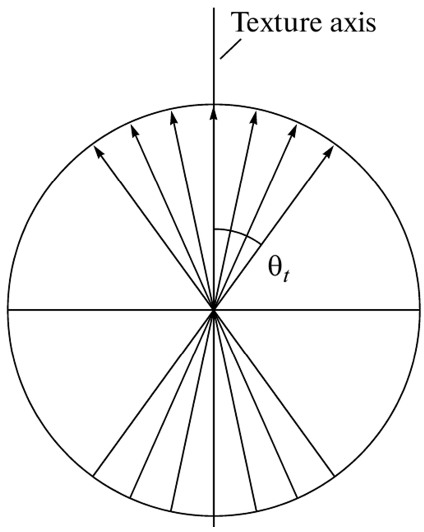

Figure 1. Orientations of the magnetic moments of monodomain uniaxial particles relative to the texture axis in an anisotropic permanent magnet.

The fabrication technique of the anisotropic powder-based permanent magnets includes alignment of monodomain uniaxial particles of hard magnetic material in the magnetic

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field, with pressing them in the oriented state [3]. As a result, the material acquires an axial magnetic texture and its perfection degree is characterized by the texture scattering angle θ_t (Figure 1) or by relative remanent magnetization M_r/M_s (M_r and M_s are the remanent and saturation magnetization of the magnet, respectively)[3].

This paper describes the Mössbauer technique that can be used in order to determine the parameters θ_t and M_r/M_s.

2. Experimental Methods

The Mössbauer technique is an effective tool for the determination of the spin structure of ferro- and ferri-magnetics [4–10]. The reason for this fact is that the direction of the hyperfine field at the ^{57}Fe nucleus is opposite to the direction of magnetization, and its temperature dependence is similar to that of spontaneous magnetization [4–8].

The relative areas of the Mössbauer Zeeman splitting lines of ^{57}Fe in uniformly magnetized sample are

$$S_{1,6} = 3(1+\cos^2\theta)$$

$$S_{2,5} = 4\sin^2\theta \qquad (2)$$

$$S_{3,4} = 1+\cos^2\theta$$

where θ is the angle between magnetization and the γ -ray direction.

If the direction of γ-ray is parallel to the direction of magnetization (θ=0), the second and the fifth lines of the Mössbauer spectrum disappear. In case when the sample is partially magnetized, the relative areas of these lines depend on the magnetization degree.

Let us consider the sample cut from a permanent magnet in the plane perpendicular to the axis of the texture. We may suppose that the spontaneous magnetization of the particles is uniformly distributed in the angle θ_t. Based on the condition that the direction of γ-ray is parallel to the axis of the texture, for the area ratio of the second absorption line to the first one (or the fifth to the sixth) of ^{57}Fe nuclear Zeeman splitting, we can write

$$k = \frac{S_{2.5}}{S_{1.6}} = \frac{4(1-\overline{\cos^2\theta_i})}{3(1+\overline{\cos^2\theta_i})}, \qquad (3)$$

where θ_i is the angle between the direction of γ-ray and the direction of spontaneous magnetization of the *i*-particle ($0 \le \theta_i \le \theta_t$)

$$\overline{\cos^2\theta_i} = \frac{\int_0^{\theta_t}\int_0^{2\pi}\cos^2\theta\sin\theta d\theta d\phi}{\int_0^{\theta_t}\int_0^{2\pi}\sin\theta d\theta d\phi} = \frac{\cos^3\theta_t - 1}{3(\cos\theta_t - 1)} \qquad (4)$$

Substituting Eq. (4) in to Eq. (3) we can obtain the equation

$$\cos^3\theta_t + \frac{9k-12}{3k+4}\cos\theta_t + \frac{8-12k}{3k+4} = 0, \qquad (5)$$

from which the angle θ_t can be determined using the parameter k. Figure 2 shows the graph of Eq.(5).

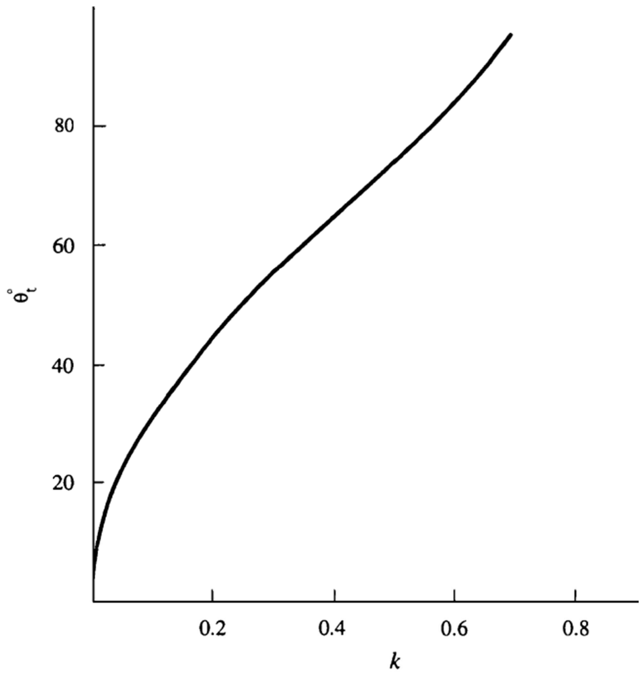

Figure 2. Texture scattering angle θ_t as a function of parameter k Eq. (5).

The direction of γ-ray is parallel to the axis of the texture, so, for relative remanent magnetization of the magnet, we can write

$$\frac{M_r}{M_S} = \overline{\cos\theta_i} = \frac{1+\cos\theta_t}{2} \qquad (6)$$

The Mössbauer spectrum does not present the distinction between symmetric and antisymmetric orientations of the magnetic moments of the particles in relation to the texture axis because the relative areas of the Zeeman splitting lines are defined by the square of trigonometric function (2) [11]. Therefore in the proposed technique of the determination of θ_t and M_r/M_s, we can use the demagnetized sample. In this case, due to the lack of the own demagnetization field of the sample, accuracy of the measurements of θ_t and M_r/M_s increases.

3. Results and Discussion

We verified the proposed methodology on the 28BA-170 and 16BA-190 grade permanent magnets based on the barium ferrite $BaFe_{12}O_{19}$ [12]. The samples were cut along the plane perpendicular to the axis of texture (samples diameter were 15mm and samples thickness were 60 µm). Mössbauer investigations were done with a ^{57}Co/Cr source driven at a constant acceleration mode.

The Mössbauer spectra of the samples (Figure 3) represents a superposition of five Zeeman sextets related to iron ions in five magnetic sublattices of barium ferrite $BaFe_{12}O_{19}$:12k, 2*a*, $4f_1$, $4f_2$,2b [8], with different hyperfine fields at nucleus - 418, 504, 490, 519, 403 kOe, respectively.

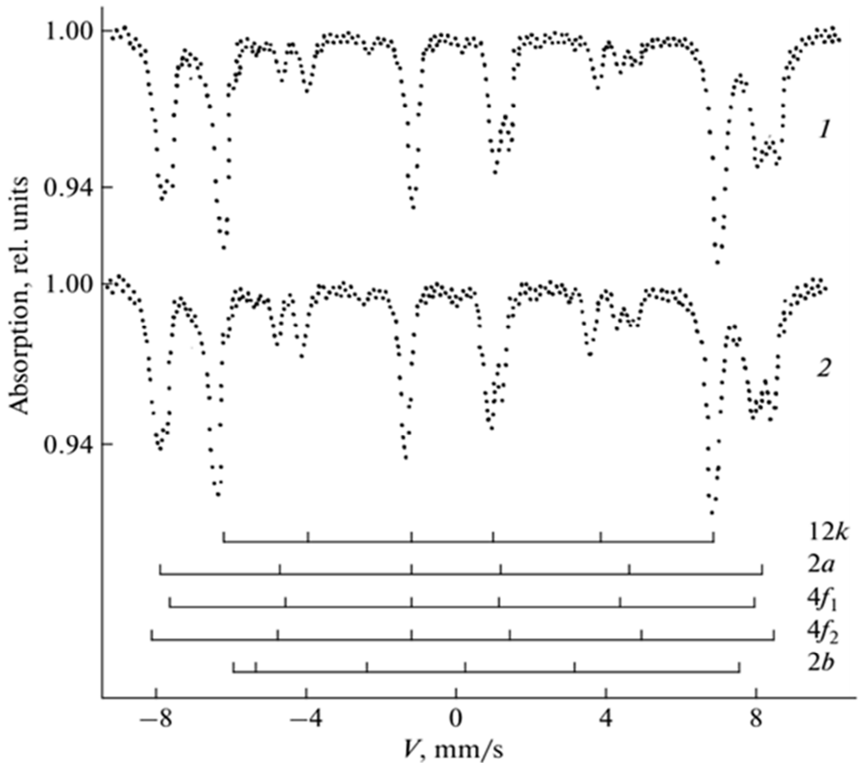

Figure 3. Mössbauer spectra of (1) 28BA-170 and (2) 16BA-190 grade permanent magnet samples. The direction of the γ-ray was parallel to the magnetic texture axis.

The spectra were analyzed by a least - squares computer program. Parameter k was determined from the integrated area ratio of the absorption lines all sextets in the Mössbauer spectrum. For the 28BA-170 and16BA-190 magnets, the results of measurements are as follows:

	θ_t	M_r/M_s
28BA-170	30° ± 3°	0.93
16BA-190	40° ± 3°	0.88

For these types of magnets, the magnetic measurements yield the following values [12]:

	M_r/M_s	M_r	M_s
28BA-170	0.93	310 G	333 G
16BA-190	0.88	238 G	270 G

The experimental results are seen to coincides with the magnetic measurements.

Therefore, the scattering angle of the magnetic texture and the relative remanent magnetization of a permanent magnet can be determined from the Mössbauer spectrum. The advantage of the Mössbauer method is the possibility of using a demagnetized sample in the measurements. Based on the described method, it is also possible to determine the degree of magnetic texture perfection in magnetically hard iron-containing alloys of various systems [3] used in production of permanent magnets.

4. Conclusions

Manufacturing of the anisotropic power-based permanent magnets includes orientation of monodomain uniaxial particles of hard magnetic material in the magnetic field and their subsequent pressing in an oriented state. This results in formation of an axial magnetic texture, the degree of perfection of which is characterized by the texture scattering angle θ_t or by relative remanent magnetization M_r/M_s (M_r and M_s are the remanent and saturation magnetization of the magnet, respectively). In this paper presents the method that can be used in order to determine the parameter θ_t and M_r/M_s of the permanent magnets using Mössbauer spectroscopy. The method has been verified on the permanent magnets made of barium ferrite $BaFe_{12}O_{19}$. The experimental results of the Mössbauer spectroscopy method are coincides with the magnetic measurements. The advantage of Mössbauer method is the possibility of using a demagnetized sample in the measurements.

References

[1] S. Krupichka, Physics of Ferrites and Magnetic Oxides, Izdatel'stvo "Mir", Moskow, 1976, P. 504.

[2] U. I. Petrov, Physics ofSmall Particles, Izdatel'stvo"Nauka", Moskow, 1982, P. 359.

[3] V. V. Sergeev, T. I. Bulygina, Magnetically Hard Materials, Izdatel'stvo "Energia", Moscow, 1980, P. 81.

[4] R. S. Preston, S. S. Hanna, J. Heberle, Phys. Rev. 128(1962)2207.

[5] F. van der Woude, G. A. Sawatzky, A. H. Morrish, Phys. Rev. 167 (1968)533.

[6] L. K. Leung, B. J. Evans, A. H. Morrish, Phys. Rev. B 8 (1973)29.

[7] S. C. Bhargava, N. Zeman, Phys. Rev. B 21 (1980)1726.

[8] P. Wartewig, M. K. Krause, P. Esquinazi, S. Rösler, R. Sountag, J. Magn. Magn. Mater. 192 (1999) 83.

[9] A. M. Afanasev, M. A. Chuev, JETP Letters, 74 (2001) 112.

[10] M. A. Chuev, JETP Letters, 83 (2006) 668.

[11] S. M. Irkaev, R. N. Kusmin, A. A. Opalenko, Nuclear Gamma Resonance, Izdatel'stvo "Moskow University", Moskow, 1970, P. 205.

[12] A. A. Preobrazhenski, E. G. Bishard, Magnetic Materials and Elements, Izdatel'stvo "VysshayaShcola", Moscow, 1986, P. 198.