Finding Out the Commonalities in Functional Expressions for Demagnetizing Factor of Quasi-solid and Solid Magnets

A.A. Sandulyak, D.A. Sandulyak, V.A. Ershova, D.O. Kiselev, A.V. Sandulyak

***Abstract* — The paper analyzes available experimental dependences of the demagnetizing factor of solid ferromagnetic samples on their relative dimension. The exponential view of these dependences has been ascertained (set for quasi-solid magnets); the relations obtained with mutually very different values of magnet matter magnetic permeability vary with the radical of the sample relative dimension.**

***Index Terms* — demagnetizing factor, magnetic permeability, relative level of magnetization.**

I. Introduction

It is well known that when we magnetize a magnetic sample of a particular form, there are poles formed at the edges of the sample which create an internal demagnetizing field, opposed to the external magnetizing one. A corresponding quantitative parameter characterizing this phenomenon is called a demagnetizing factor N (also known as the demagnetization coefficient which essentially is a parameter of magnetization suppression); this factor relates the demagnetizing field intensity with the sample magnetization. For example, the analytically calculable values of N for a ball, a cross-wisely magnetized long cylinder and a thin plate amount to N=1/3, N=1/2, N=1 [1-4] respectively.

For the samples of other forms, the factor is defined experimentally. In such a case it is always actual to obtain analytical (describing some experimental data) dependences apt for various calculations applicable to different samples of particular shapes and sizes.

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II. Results and discussions

To ascertain how great the influence of the demagnetizing factor N on the level of sample magnetization is, it is enough to turn to a classical expression for parameter N:

$$N = \frac{1}{\mu_N - 1} - \frac{1}{\mu - 1}, \tag{1}$$

which shows the connection of N and magnetic permeability of the matter μ and that of the sample – body μ_N [1, 5-9]. Then, by the formula obtained in (1):

$$\frac{\mu_N}{\mu} = \Lambda = \frac{1}{\mu}\left[\frac{\mu - 1}{(\mu - 1)N + 1} + 1\right] \tag{2}$$

for a particular sample we can define such essential parameters as a relative level of magnetic permeability μ_N/μ and thus, a relative level of magnetic induction B_N/B, i.e. their real (reduced) values in comparison with potential ones. Herewith, the identity of these parameters, viz. $\mu_N/\mu=B_N/B=\Lambda$ follows from $B_N=\mu_0\mu_N H$ and $B=\mu_0\mu H$, where μ_0 is a magnetic constant and H is the magnetizing field intensity.

Basing on formula (2) we can illustrate (Fig. 1) to which extent the level of sample-body magnetization Λ depends on the demagnetizing factor N, e.g. for the samples with greatly varying values of magnetic permeability of their matter, say with μ=5, μ=10 and μ=100. We can clearly see in Pic. 1 that N is really the factor which even with seemingly small values, let alone increased or big ones, is able to sufficiently suppress the magnetic properties of the magnet. The N value of a given sample-body in its turn varies with its form and is mainly defined experimentally, as stated above.

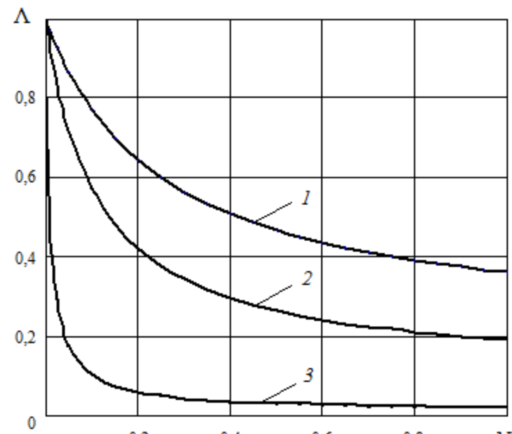

Fig. 1. Demonstrating the influence of the demagnetizing factor of the magnet sample (body) on the relative level of its magnetization; 1 – μ=5, 2 – μ=10, 3 – μ=100.

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As to the employing certain obtained experimental data on N (most often these are the values for longitudinally magnetized cylindrical samples with given values of length L and diameter D, i.e. the relative dimension L/D), provided the data is in good supply, it will be necessary to derive a relevant generalizing formula for calculating N. Such a formula with introduced dimensionless argument L/D may be integrated in formula (2), thus instantiating it for the samples of any particular form in question.

Among the formulae connecting N and L/D parameter, one original equation is noteworthy, it is the one obtained for specific magnets: porous (granular) samples [10], for which (as for quasi-solid bodies) the issue of a demagnetizing factor influence has been less well understood than for solid magnets. Actually, a systematic study of the matter was initiated in [7] due to increased use of matrix magnetic separators, or filter-type separators [11-15]. The magnetized matrix (a loading of granules) performs a targeted capture of ferroparticles (ferroimpurities). Thus, as applied to the sample bodies of these magnets (a loading of ball-bearing balls) of a cylindrical form of various L/D values, field dependences of induction have been obtained experimentally [7]. In paper [10], using these data in [7] and proceeding to field dependencies of permeability, we calculated explicit values of N by (1). A respective processing of these data revealed that N dependency on L/D has an exponential view but with such a rather unusual argument as a radical of the relative dimension [10]:

$$N = \exp\left(-k_N\sqrt{\frac{L}{D}}\right), \tag{3}$$

with the value of coefficient $k_N \cong 1{,}5$ integrated in (3); it is for the studied quasi-solid samples in a comparatively narrow range of μ=6.9 – 8.5 [7].

Moreover, formula (3) proved to be highly applicable not only to the samples of a granular medium, but also to various quasi-solid cores of ball-granule chains as well (as to an element of a bundled chains in a real granular medium [10]). Meanwhile, the values of metal volume concentration γ for a conditionally cut out core of the balls chain are different (in contrast to granular media, where $\gamma \cong 0.6$). They vary from γ=0.66 for a solitary chain up to $\gamma \rightarrow 1$ when thinning out at its core part in a paraxial area of the chain, i.e. with a sharp decrease of a wedge-gap between the granules and thus with approximation of the core to the state of a solid metal.

This fact should be considered especially noteworthy as it gives grounds to assume that the obtained relation (3) may prove true not only for quasi-solid but also for solid magnet samples as well.

To test the assumption, it is necessary to have at one's disposal relevant experimental data on the demagnetizing factor N, e.g. for solid cylindrical samples in relation to their relative dimension L/D.

For this purpose, we can use classical experimental data, [4, 8] to be exact, shown in Fig. 2. Here, if we again employ the results obtained for the samples with reciprocally far too different values of magnetic permeability of their matter (Fig. 2), e.g. μ=5, μ=10 and μ=100 congruently to the case considered above, then by formula (2) for starters we can find a relative level of magnetization Λ (Fig. 3), but now depending on L/D.

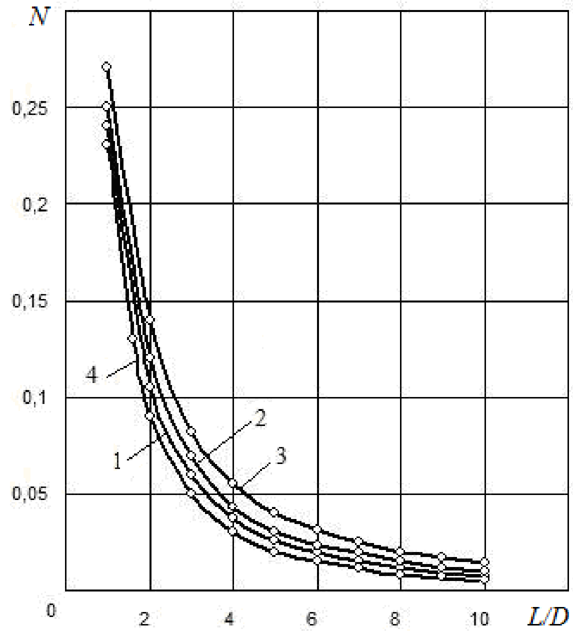

Fig. 2. Experimental data on the demagnetizing factor of ferromagnetic cylindrical samples varying with their relative dimension; curves 1, 2, and 3 correlate to values μ=5, μ=10, μ=100 respectively and are taken from [4], curve 4 is the data from [8], the value of μ in [8] is regrettably not stipulated.

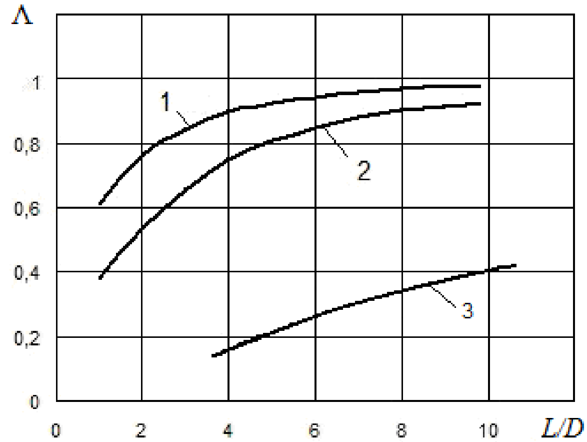

Fig. 3. Illustration of the alterations in values of the sample magnetization relative level depending on their relative dimension, by data in Fig. 2 with using (2); 1 – μ=5, 2 – μ=10, 3 – μ=100.

It can be seen that with reduction of relative dimension L/D of the sample and judging by the decrease of Λ parameter (Fig. 3), its magnetic properties (μ_N and B_N) are more and more giving in to the magnetic properties of the matter (μ and B). And vice versa, with increase of L/D magnetic properties of the sample and its matter come closer, and with this growth μ zone of almost complete convergence moves towards bigger values of L/D. So, for relatively low values of μ=5-10 (Fig. 3, curves 1 and 2) magnetic properties of the sample and its matter practically become sufficiently close with $L/D \approx 10$. As for increased and big values of μ, e.g. for μ=100 (Fig. 3, curve 3) this kinship is reached with higher values of L/D. By the way, this is why a well-known rule is justified, it being the rule that recommends taking quite long samples ($L/D \geq 50$) to study magnetic properties of such ma-

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terials in case when we use cylindrical instead of classic toroidal samples.

Having factual data on the demagnetizing factor N for cylindrical magnets (let us repeat, the values lie in a rather wide range of magnetic permeability of the matter μ=5-100), with the data obtained with various values of relative dimension L/D of these samples (Fig. 2), we can now test the above stated assumption on a possible universalization of expression (3), i.e. making it applicable to the samples of solid magnets. For this purpose, the data represented in Fig. 2 (curves 1-3) have to be represented in the same semi-logarithmic coordinates which are used for granular magnets [10], assuming the radical of relative dimension L/D, i.e. $\sqrt{L/D}$ (Fig. 4) to be an argument. Herewith, the mandatory reference point of N=1 with $L/D\to 0$ just as in the case for a thin plate should serve the principle check point [10].

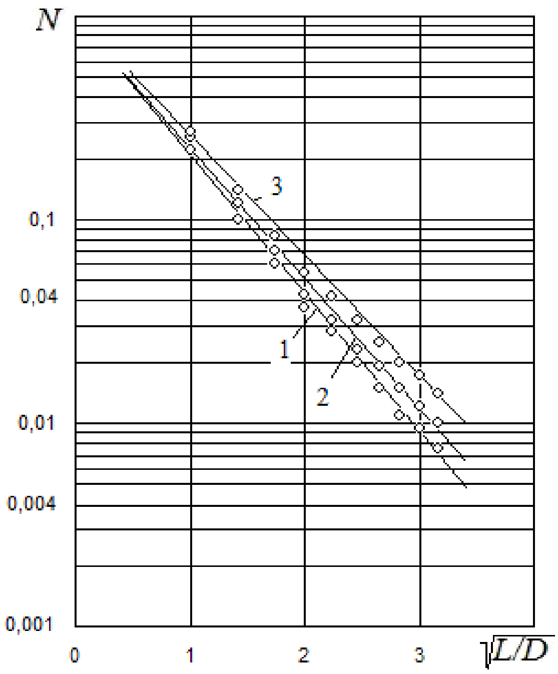

Fig. 4. Data on the demagnetizing factor of the samples (Fig. 2) represented in semi-logarithmic coordinates as related to the radical of their relative dimension. The linearization phenomenon is the manifestation of exponential dependence.

In these coordinates the data on N are seen to linearize quite well, thus signifying the validity of relation (3) and now even for solid magnets as well. It means we can speak of the exponential relation of N with the indicated argument-radical ($\sqrt{L/D}$) as of a universal regularity.

III. Conclusion

The original functional dependence (3) instigated the current research aimed at enhancing the understanding of the role and behavioural patterns of the demagnetizing factor for various magnetic bodies. Obtained for specific magnets, viz. granular ferromagnetic samples (as quasi-solid magnets) and 'packed' cores of granules chains (as the constituting elements of these magnets), the formula indicates exponential connection between demagnetizing factor N and the radical of their relative dimension, $\sqrt{L/D}$.

The assumption about a possible applicability of this functional dependence (3) with respect to solid samples proved to be valid for the most part. We managed to get the following results from the analysis of a number of experimental dependences of the demagnetizing factor N for solid ferromagnetic cylindrical samples on their relative dimension L/D:

– We have confirmed the commonality of the functional view (3) of the demagnetizing factor N for quasi-solid and solid ferromagnetic cylindrical samples dependence on their relative dimension L/D; the view is exponential with the radical of the relative dimension $\sqrt{L/D}$ being the argument.

References

[1] K. Smistrup, O. Hansen, H. Bruus, M. Hansen, "Magnetic separation in microfluidic systems using microfabricated electromagnets – experiments and simulations", in *Journal of Magnetism and Magnetic Materials*, vol. 293, 2005, pp. 597-604.
[2] F.J. Presuel-Moreno, A.A. Sagues, "Bulk magnetic susceptibility measurements for determination of fly ash presence in concrete", in *Cement and Concrete Research*, 2009, vol. 39 (2), 2009, pp. 95-101.
[3] M. Anhalt, B. Weidenfeller, J.L. Mattei, "Inner demagnetization factor in polymer-bonded soft magnetic composites", in *Journal of Magnetism and Magnetic Materials,* vol. 320, 2008, pp. 844-848.
[4] I.I. Kifer, "Ferromagnetic materials testing", 3rd edition. Moscow: Energy, 1969, 360 p.
[5] K. Nandy, S. Chaudhuri, R. Ganguly, I.K. Puri, "Analytical model for the magnetophoretic capture of magnetic microspheres in microfluidic devices", in *Journal of Magnetism and Magnetic Materials*, vol. 320, 2008, pp. 1398-1405.
[6] R. Goleman, "Macroscopic model of particles' capture by the elliptic cross-section collector in magnetic separator", in *Journal of Magnetism and Magnetic Materials*, vol. 272-276, 2004, pp. 2348-2349.
[7] A.V. Sandulyak, "Purification of liquids in a magnetic field", Lvov: Higher School Publishing House at Lvov University, 1984, 167 p.
[8] D.-X. Chen, J.A. Brug, R.B. Goldfarb, "Demagnetizing factors for cylinders", in *IEEE Transactions on Magnetics*, vol. 27, No. 4, 1991, pp. 3601-3619.
[9] D.-X. Chen, E. Pardo, A. Sanchez, "Fluxmetric and magnetometric demagnetizing factors for cylinders", in Journal of Magnetism and Magnetic Materials, vol. 306, 2006, pp. 135-146.
[10] A.A. Sandulyak, V.A. Ershova, D.V. Ershov, A.V. Sandulyak, "On the properties of short granular magnets with unordered granule chains: a field between the granules", in *Solid State Physics*, vol. 52, Issue 10, 2010, pp.1967-1974.
[11] A.A. Sandulyak, A.V. Sandulyak, "Prospects of employing magnetic filter-separators for purifying ceramic suspensions", in *Glass and Ceramics*, No.11, 2006, pp.34-37.
[12] A. Newns, R.D. Pascoe, "Influence of path length and slurry velocity on the removal of iron from kaolin using a high gradient magnetic separator", in *Minerals Engineering*, vol. 15, 2002, pp. 465-467.
[13] J.G. Rayner, T.J. Napier-Munn, "A mathematical model of concentrate solids content for the wet drum magnetic separator", in *International Journal of Mineral Processing*, vol. 70, 2003, pp. 53-65.
[14] D. Norrgran, "Magnetic filtration: producing fine high-purity feedstocks", in *Filtration and Separation*, vol. 45 (6), 2008, pp. 15-17.
[15] V. Zezulka, P. Straka, P. Mucha, "A magnetic filter with permanent magnets on the basis of rare earth", in *Journal of Magnetism and Magnetic Materials*, vol. 268, 2004, pp. 219-226.