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RESEARCH ARTICLE

METHOD FOR CALCULATING MAGNETIC INDUCTION OF CYLINDRICAL HEARTONS FROM CRITICAL MAGNETIC HARD MATERIALS

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ABSTRACT

At this time in the field of instrumentation technology, the creation of advanced instruments is very important. On this basis, the article considers the necessary determination of the values of the main parameter of the power characteristics of the interaction between a solenoid and a magnetic core of magnetic levitation systems - magnetic induction of the core. The ability to measure the level and density of a buoy magnetolovitsionnym level sensor in ship tanks gives this device a huge number of positive features due to a levitating body, which is a sensitive element that can be placed on various measuring chambers. The method of calculation is based on using the demagnetization curve of the hysteresis loop of the magnet material.

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INTRODUCTION

One of the main parameters of the power characteristics of the interaction of the solenoid and the magnetic core of magnetic levitation systems (SML) is the magnetic induction of the core B_M. In this regard, there is a need to determine the significance value of B_M depending on the material, the size and shape of the magnetic core. The method of calculating the magnetic induction of the B_M core is based on the use of the "back" of the demagnetization curve (return) of the hysteresis loop of the magnet material. The demagnetization curves of the main magnetically hard materials are presented in the reference book on permanent magnets (Permanent magnets, 1980). Despite the variety of forms, all the demagnetization curves are fairly accurately approximated by two straight lines 1 and 2 (Fig. 1) and an arc of a circle 3 at the intersection of these straight lines (Arkadyev, 1985; Kolesov, 2004). In accordance with this, depending on the location of the bend of the 3 demagnetization curves, all hard magnetic materials used for permanent magnets are usually divided into two groups I and II. For materials of group I, the bend of the demagnetization curve lies in the third quadrant, and its portion within the second quadrant is straight-line. In materials of group II, the bend of the demagnetization curve is located in the second quadrant and its section within this quadrant is substantially non-linearized, having a bulge in the zone of the location of the knee. Materials of the first group are called supercritical. It includes materials with a high coercive force H_{cf} (alloys of rare earth materials, barium ferrites, alloys based on manganese GYU., etc.). For them, $H_{cf} = 100 - 1000$ kA/m. Materials of group II are called subcritical. It includes materials with low coercive force (alnico, magneto, etc.). For them, $H_{cf} \leq 100$ kA / m. This classification of materials is to a certain extent arbitrary and allows determining the assumed H_{cf} shape of the demagnetization curve by value, which is especially simple for supercritical materials, which includes 71GYU alloys used in the SML under study. The method of calculating the magnetic induction of a B_M core along the B (H) demagnetization curve is based on the use of the idea of a demagnetizing factor, called the method of Arkadyev (1985). This method is applicable to magnets, in which the magnetization vector is the same in magnitude and direction in the entire volume of the magnet. Of the bodies of finite form, only an ellipsoid magnetized along one of the axes corresponds to this definition. The idea of the method is based on the fact that an internal demagnetizing field arises in a magnet of finite form with an intensity H directed against the magnetic induction vector of the magnet and proportional to its residual magnetization J.

$H = N \cdot J$ or $H = J/m$,

Where N – coefficient of proportionality is, called the demagnetizing factor;

$m = 1/N$ – shape permeability.
The values of N and m depend on the shape and ratio of the main dimensions of the bar magnet.

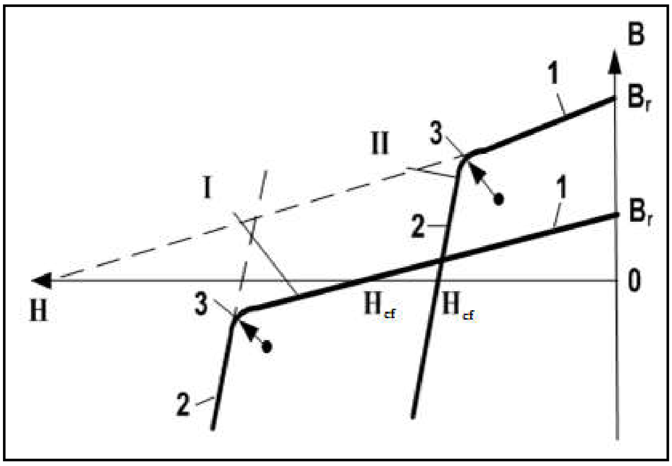

Fig. 1. Demagnetization curves of supercritical I and subcritical II of hard magnetic materials

The greater the length of the magnet relative to the area of its cross section, the smaller N or the larger m. The m value is more convenient for calculation. The calculation of the permeability of form m for magnets, the shape of which is different from the ellipsoid, is carried out using empirical formulas or graphs. The permeability of the m_c cylinder shape is found from the experimental Thompson and Moss curves with the amendment Arkadyev (1985). They determine the dependence of m_c on its relative length λ, determined by the relation:

$$\lambda = \frac{b}{\sqrt{S_м}} = \frac{b}{r_м \cdot \sqrt{\pi}}$$

where b – magnet length;
$S_м$ – magnet cross-sectional area;
$r_м$ – magnet radius.

Operating range of relative lengths λ modern bar magnets usually range from λ=1 до λ=10. Within these limits, the permeability of the cylinder shape is well approximated by the dependence

$$m_c = \frac{(1.06.\lambda)^2 - 1}{\frac{1.06.\lambda}{\sqrt{(1.06.\lambda)^2 - 1}}.\ln\left[1.06.\lambda + \sqrt{(1.06.\lambda)^2 - 1}\right] - 1} + 0.9.\lambda.e^{-0.2.\lambda},$$

which is presented graphically in Fig. 2

Since the residual magnetization $J = \frac{B_м}{\mu_0}$, that $H_м = \frac{B_м}{m_c \cdot \mu_0}$ and then the magnetic induction of the cylindrical core will be equal to $B_м = m_c.\mu_0.H_м$. The essence of the method is that in the second quadrant, where the demagnetization curve of the magnet material is placed, a straight line is drawn from the origin of coordinates, corresponding to the dependence of the magnetic induction $B = m_c.\mu_0.H$, called the straight bevel (Fig. 3). The point of intersection of the straight bevel with the demagnetization curve determines the magnetic induction of the core $B_м$ depending on m_c (λ), the value of which determines the residual magnetization J. The graphical method for determining $B_м$ implies the availability of data on the shape of the demagnetization curve of the material. For most modern materials, these data are given in reference books on permanent magnets (Permanent magnets, 1980).

RESULTS AND DISCUSSION

If the magnet material belongs to the supercritical group, then the demagnetization curve is a straight line passing through the points of residual magnetic induction Br and the coercive force H_{cf} located on the axes of the coordinates (Fig. 3). In this case, besides the graphic method, an analytical method for solving this problem can also be used.

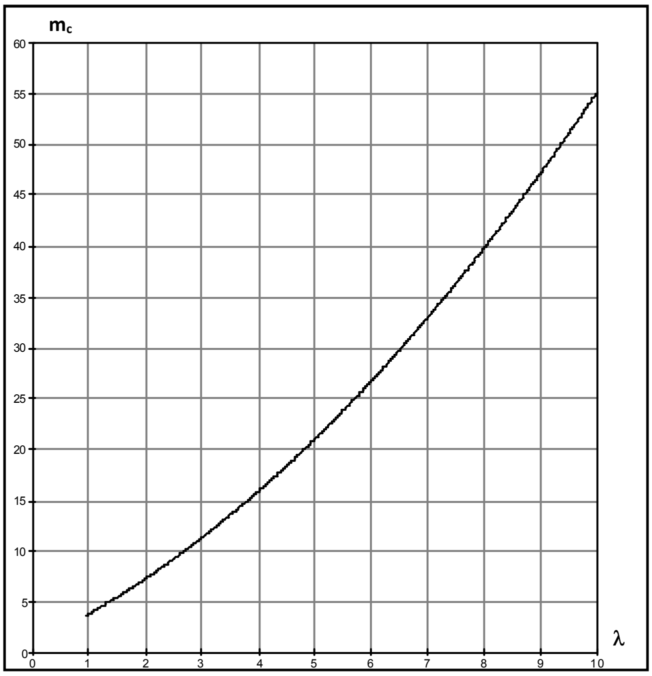

Fig. 2. A graph of the dependence of the permeability of the form m_c on the relative lengths λ of cylindrical rod magnets

Value $B_м$ is the result of the joint solution of 2 equations:

- Straight bevel:

$$B_м = m_c.\mu_0.H_м, \quad (1)$$

Held at an angle α , determined by the formula:

$$tg(\alpha) = \frac{B_м}{H_м} = m_c.\mu_0,$$

- Direct return hysteresis loop held at an angle β, determined by the formula:

$$tg(\beta) = \frac{B_r}{H_{cf}}$$

As a result, we get:

$$B_м = B_r - \frac{B_r}{H_{cf}}.H_м, \quad (2)$$

Where $H_м$ – field strength for magnetic induction $B_м$;

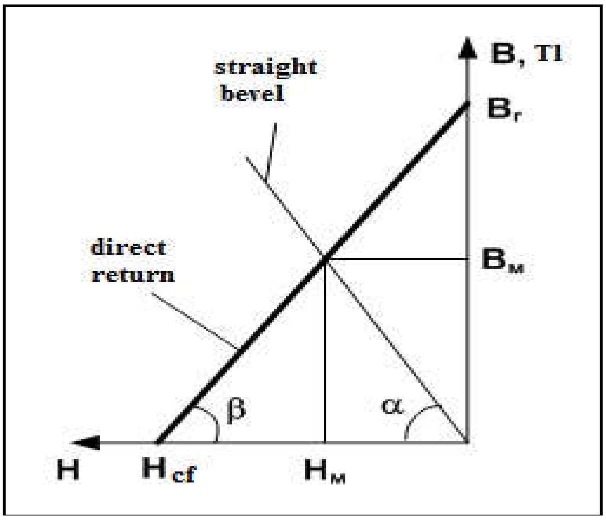

Fig.3. Graphical method of calculating the residual magnetic inductance $B_м$ cylindrical rods of supercritical magnetically hard materials

From (3.) find the field strength $H_м$:

$$H_м = \frac{H_{cf}}{B_r}.(B_r - B_м) \qquad (3)$$

Substituting (3) in (1), get:

$$B_м = \mu_0.m_c.\frac{H_{cf}}{B_r}(B_r - B_м)$$

Or

$$B_м.(1+\mu_0.m_c.\frac{H_{cf}}{B_r}) = \mu_0.m_c.H_{cf} \qquad (4)$$

Denote

$$B_r = \mu_0.\mu.H_{cf}, \qquad (5)$$

Where μ - magnetic permeability of the magnet material. Then

$$\frac{H_{cf}}{B_r} = \frac{1}{\mu_0.\mu}. \qquad (6)$$

Substituting (6) in (4), after transformation we get

$$B_м = \frac{\mu_0.m_c.H_{cf}}{1+\frac{m_c}{\mu}} = \frac{\mu_0.m_c.\mu.H_{cf}}{\mu + m_c} \qquad (7)$$

Then given (5) get out (7)

$$B_м = \frac{m_c}{m_c+\mu}.B_r, \qquad (8)$$

Where from (6)

$$\mu = \frac{B_r}{\mu_0.H_{cf}} \qquad (9)$$

For alloy 71 GYU according to reference data (Permanent magnets, 1980; Arkadyev, 1985) we find B_r = 0.5 – 0.65Tl; H_{cf} = 120 – 200 кА/м and determine the magnetic permeability of the magnet material

$$\mu = \frac{0.5 \div 0.65}{4\pi.10^{-7}(120 \div 200).10^3}\frac{Tl}{\frac{Гн.А}{м^2}} = \frac{0.5 - 0.65}{0.15 \div 0.25} = 3.3 \div 2.6$$

Choosing the average value $\mu = 3$, we get

$$B_м = \frac{m_c}{m_c+3}.B_r,$$

$m_ц$ where is determined by the schedule (Fig. 2.) depending on the relative length of the rod λ. The material used for the 71 GYU magnet belongs to the group of deformable supercritical hard magnetic materials - manganese alloy 71% and aluminum 29%. The return curve of its hysteresis loop should be taken close to the straight line located in the second quadrant.

For selected magnetic core sizes b = 33 мм and $r_м$ = 2.65 мм find the value of the relative length of the core $\lambda = \frac{33}{2.65 \cdot \sqrt{3.14}} = 7$.

From the graph (Fig. 2) for λ = 7 we find m_c = 33.

Then from (8)

$$B_м = \frac{33}{33+3}.B_r = 0.92 \quad B_r = (0.46 - 0.6)Tl.$$

These values are chosen as the basis for calculating the traction characteristics of the MSS solenoid. Thus, this method of calculation is based on the premise of the linear dependence of the return function in the second quadrant of the hysteresis loop and can be extended to any highly coercive alloys belonging to the group of supercritical materials. In the case of a nonlinear dependence of the return function, an error of the analytical method appears, which is greater, the greater the convexity of the function.

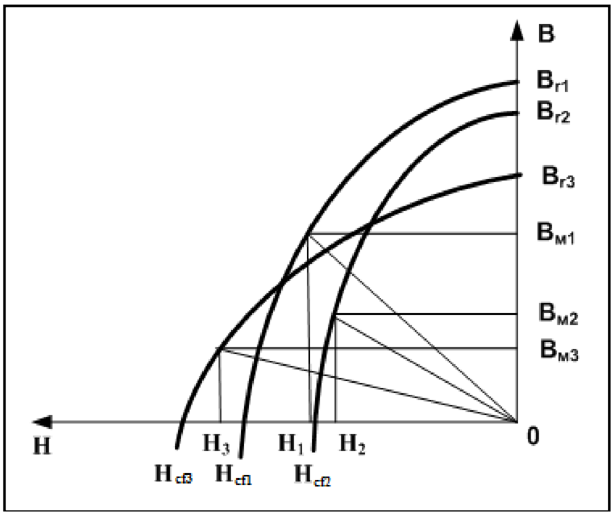

Fig. 4. Illustration of a graphical method for determining the residual magnetic Induction $B_{мi}$ of cylindrical subcritical rods hard magnetic materials

In this case, it is necessary to return to the graphical method (Fig. 4). However, it is naturally necessary to know the shape of the return curve, which for many materials is given in the reference book (Kunevich *et al.,* 2004).

Conclusion

The article defines the values of the main parameter of the power characteristics of the interaction of the solenoid and magnetic core of magnetic levitation systems - magnetic induction of the core. And also produced a graphical method of calculating the residual magnetic induction of cylindrical rods of supercritical hard magnetic materials. The calculation method proceeds from the premise of the linear dependence of the return function in the second quadrant of the hysteresis loop and can be extended to any highly coercive alloys belonging to the group of supercritical materials. In the case of a nonlinear dependence of the return function, an error of the analytical method which is greater appears, the convexity of the function is more greater.

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