Automatic Setting the Magnetic Induction Amplitude When Testing Electric Steel

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Abstract. Problems of a measurement automation of magnetic characteristics of electrical steels are considered. Efficiency of some known iterative methods for the setting a required amplitude value of a magnetic induction of tested material is explored. It’s shown that the most effective method from explored ones, realizing the fast and stable convergence of iterative process on trials both textured and isotropic electrical steels is the method of parabolas.

Introduction

According to the accepted rules, the operating under a program procedure of trials of electrical steel should realize: 1 – setting the necessary amplitude value B_m and the sine shape of a curve of a magnetic induction of material; 2 – measuring, a calculation and an analysis of a magnetic hysteresis and its parameters (for example, a value of magnetic losses) with the observance of the condition 1. Setting required values B_m is connected with finding correspondent to them on the basic magnetization curve (BMC) amplitude values of the magnetic field intensity H_m:

$$B_m = B(H_m), \tag{1}$$

So that the equality was fulfilled:

$$B(H_m) - B_m = 0 \tag{2}$$

For the equation solved by an iterative method the expression (2) may be presented as:

$$f(x) = B(x) - B_m, \tag{3}$$

where x is a required field H_m, B_m is the set value of a magnetic induction.

The analysis of an application efficiency of known iterative methods for a determination H_m at which setting the desired value B_m is ensured is carried out in the work. Efficiency of usage of the method was understood as a high accuracy of setting the desired value B_m at inconvertible and fast convergence of an iterative process. The purpose of the work was the determination of most effective of these methods.

1 Basic Positions

1.1 A Procedure of Examinations

When carrying out examinations the modified approximating expression for BMC electrical steel [1] was used:

$$B(H)=\mu_0\left(H+\frac{J_s}{2\cdot\pi\cdot C}\cdot\left[\sqrt{K_1}\cdot\ln\left(\frac{H^2+2\cdot H\cdot C\sqrt{K_2}+K_2}{H^2+2\cdot H\cdot C\sqrt{K_2}+K_2}\right)\right]+\right.$$

$$\left.+2\cdot C\cdot arctg\left(\frac{H^2-K_2}{2\cdot H\sqrt{K_1K_2}}\right)+\pi\cdot C\right), \qquad (4)$$

where J_s – a magnetization of technical saturation, μ_0 – a permeability of vacuum, $C=\sqrt{1-K_1}$, K_1, K_2 – coefficients of approximation, constant for the given material. For example, for textured electrical steel $K_1 = 0{,}018$; $K_2 = 2{,}321\cdot10^4$. In a Fig. 1 the magnetization curve for textured anisotropic steel (the curve A) constructed from the expression (4) which has good concurrence with the experimental BMC is presented. Here too, in a Fig. 1, the curve of the relative differential magnetic permeability of the given material (the curve B), calculated on BMC from the expression (5) is presented:

$$\Delta\mu=\frac{1}{\mu_0}\frac{dB}{dH} \qquad (5)$$

BMC, represented on a Fig. 1 (the curve A) as a whole has nonlinear character, therefore at setting the values B_m located in its various points, conditions for embodying iterative processes will be different. For examination of a velocity and a stability of a convergence of a iterative process in deciding on a set value B_m in any point BMC 5 characteristic areas have been allocated on the curve A of a Fig. 1: 1 – the area of a initial magnetization; 2 – the area of a passage to the greatest permeabilities; 3 – the area of the greatest permeabilities; 4 – the area of an approximation to a technical saturation; 5 - the area of a technical saturation. The areas 1, 3, 5 of BMC in a Fig. 1 have character, close to linear, the areas 2, 4 - are non-linear. In each of five separated areas of BMC the value of a magnetic field strength H_{mi} which was considered as a solution of an iterative method was chosen, i.e. at its substitution the equality (2) should be fulfilled. As such fields their

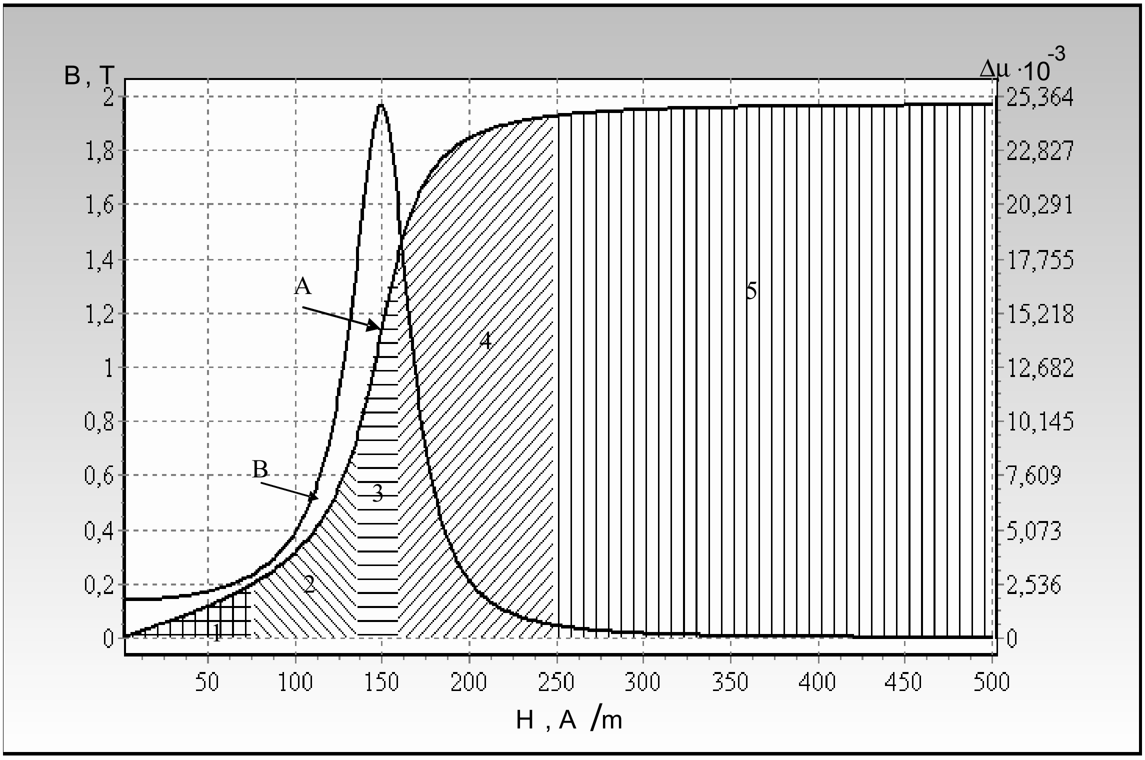

Fig. 1 - The basic magnetization curve (A) and the dependence of the relative differential magnetic permeability of textured electrical steel on a magnetic field strength (B)

maximum values i.e.: H_{m1}=75 A/m, H_{m2}=135 A/m, H_{m3}=160 A/m, H_{m4}=250 A/m have been selected from four first areas. The value of the field H_{m5}= 450 A/m has been selected from the fifth area. The following values of a magnetic induction B_{mi}: B_{m1}=0,197 T, B_{m2}=0,726 T, B_{m3}=1,428 T, B_{m4}=1,927 T, B_{m5}=1,965 T which were considered as set ones in a iterative process corresponded on BMC to indicated above values of a magnetic field strength H_{mi}. Chosen areas of BMC were divided into 4 equal parts with a pitch of a partition: $h_i = \left(H_{\max i} - H_{\min i}\right)/4$ along abscissa, and for each area values of a magnetic field strength $H_{nij} = H_{\min i} + jh_i$ which were chosen as initial approximations in iterative methods were calculated in three first points. Numerical values H_{nij} are presented in table 1, where i – the area number of a partition, and j – the point number of an initial approximation.

Table 1. The values of a magnetic field strength selected as initial approximations.

i j	1	2	3	4	5
1	18,75	90	141,25	182,5	300
2	37,5	105	147,5	205	350
3	56,25	120	153,75	227,5	400

Thus, the procedure of an operation was reduced to that the mentioned above values of a magnetic induction $B_{m1} - B_{m5}$ were set sequentially, and for each of them iterative processes were explored for different values of a field of an initial approximation H_{nij}. In this case, the velocity and a degree of a stability of a convergence of an iterative process, i.e. a determination of its solution as the corresponding fields $H_{m1} - H_{m5}$ for all methods were analysed.

1.2 Explored Methods

1 Newton's method

$$x_n = x_{n-1} - \frac{f(x_{n-1})}{f^{'}(x_{n-1})}, \tag{6}$$

where $n = 1, 2, ..N$ is the number of iteration, $x_0 = H_{nij}$

2 Method of secants

$$x_n = x_{n-1} - \frac{f(x_{n-1}) \cdot h}{f(x_{n-1}) - f(x_{n-1} - h)}, \tag{7}$$

where $n = 1, 2, ..N$ is the number of iteration $x_0 = H_{nij}$, h is some small parameter of a method which is chosen from a requirement of the most precise evaluation of a derivative.

3 Vegstain's method

$$x_n = x_{n-1} - \frac{f(x_{n-1}) \cdot (x_{n-1} - x_{n-2})}{f(x_{n-1}) - f(x_{n-2})}, \tag{8}$$

where $n = 1, 2, ..N$ is the number of iteration, $x_0 = H_{nij}$

4 Method of parabolas

$P_2 = p(x - x_3)^2 + q(x - x3) + r = pz^2 + qz + r$ is the polynomial of 2-nd order which has two radicals $z^{1,2}{}_m = \frac{-q \pm \sqrt{q^2 - 4pq}}{2p}$, the following pitch $x_4 = x_3 + z_m$ was calculated, where z_m is the least radical in modulus.

$$x_n = x_{n-1} + z_m(x_{n-1}, x_{n-2}, x_{n-3}), \tag{9}$$

where $n = 1, 2,..N$ is the number of iteration, $x_0 = H_{nij}$

5 Method of the linear interpolation

a. Calculate for x_0=0; $y_0 = f(x_0)$; $x_1 = H_{nij}$, $y_1 = f(x_1)$

b. Calculate: $x_2 = x_1 - \frac{y_0(x_1 - x_0)}{y_1 - y_0}$, $y_2 = f(x_2)$

c. Pick a direction of driving to the radical: if $y_0 y_2 > 0$, then $x_1 = x_2$ $y_1 = y_2$, otherwise $x_0 = x_2$, $y_0 = y_2$.

d. The radical $x^* = x_2$ if the given accuracy does not satisfy, b, c items are iterated.

6 Rider's method

$$x_n = x_{n-1} + (x_{n-1} - x_{n-3}) \frac{sign(f(x_{n-3}) - f(x_{n-2})) \cdot f(x_{n-1})}{\sqrt{f^2(x_{n-1}) - f(x_{n-3}) \cdot f(x_{n-2})}}, \tag{10}$$

where $n = 1, 2,..N$ is the number of iteration, $x_0 = H_{nij}$

7 Method of a bisection

a. Calculate $y_0 = f(x_0)$ $x_1 = H_{nij}$, $y_1 = f(x_1)$

b. Find the following point as a bisecting one of a segment: $x_2 = (x_0 + x_1)/2$,

c. Pick a direction of driving to the radical: if $y_0 y_1 > 0$, then $x_0 = x_2$, $y_0 = y_2$, otherwise $x_1 = x_2$, $y_1 = y_2$.

d. The radical $x^* = x_2$ if the given accuracy does not satisfy it's iterated b, c items.

2 Outcomes of Examinations

2.1 Textured Electrical Steel

At examination of methods, as well as in [2] the iteration number dependency of the reduced error was plotted. The reduced error was understood as the ration of the absolute errors of the n-th iteration to the first one:

$$En(n) = \frac{x_n - H_{mi}}{x_0 - H_{mi}} , \tag{11}$$

where n is the iteration number, x_0 is an initial approximation, x_n is an approximation on the n-th iteration, H_{mi} is the precise solution corresponding to the set magnitude of a magnetic induction B_{mi} in the i-th area. For the greater obviousness all dependences En on an axis of ordinates were represented in a logarithmic scale to the base ten. In the Fig. 2 (a, b, c, d, e) character of behavior of iterative methods is shown at a determination of fields $H_{m1} - H_{m5}$ for the setting amplitude values of a magnetic induction B_{m1}, …, B_{m5}. As an initial approximation for all cases it was sampled the field $H_{nij} = H_{n11} = 18{,}75$ A/m (the table 1). On an abscissa axis of a Fig. 2 the number of iterations, on an axis of ordinates - the reduced error of a determination of a desired value of magnetic field strength H_{mi} are

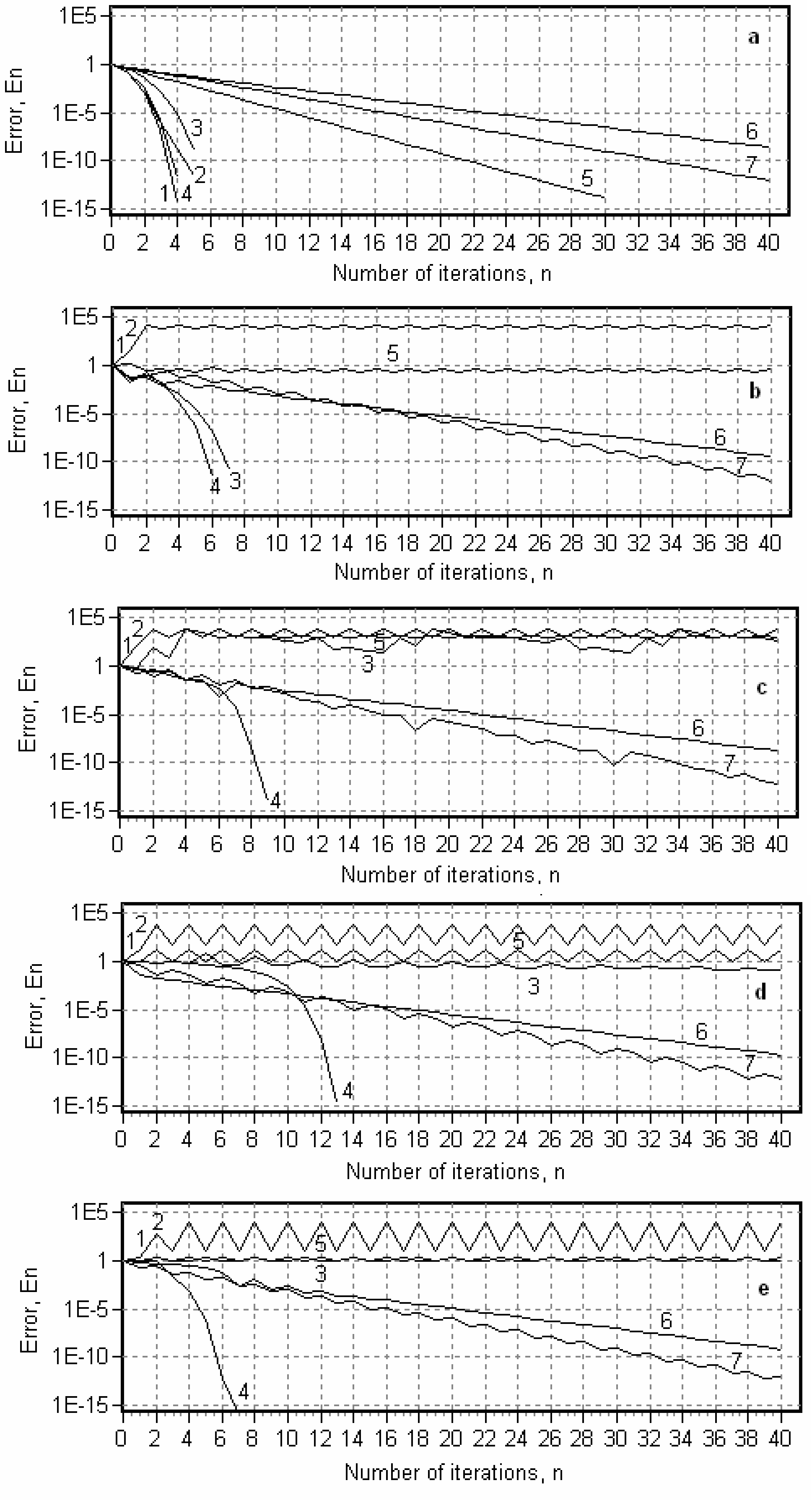

Fig. 2 - Character of behaviour of iterative methods at setting the amplitude values B_m of a magnetic induction in textured electrical steel: a – $B_m = 0{,}197$ T; b – $B_m = 0{,}726$ T; c – $B_m = 1{,}428$ T; d – $B_m = 1{,}927$ T; e – $B_m = 1{,}965$ T.

plotted. 1-7 Numerals designate the curves describing a iterative process at usage of the methods, indicated in 1.2. From the Fig. 2 it is visible, that the most effective iterative method is the fourth - one of parabolas having the greatest velocity and a stability of a convergence of an iterative process. The analysis of the obtained results in all volume of examinations shows, that the method of parabolas is not only the most effective, but also rather convenient, since at setting any value of a magnetic induction B_m on BMC (the curve A Fig. 1), the field of an initial approximation H_{nij} can be remained constant in the beginning of a magnetization curve.

2.2 Isotropic Electrical Steel

In the work effectiveness of methods surveyed above as applied to isotropic electrical steel is explored. In the Fig. 3 the basic magnetization curves (A) and a differential magnetic permeability one (B) for isotropic electrical steel are presented. The curve A of the Fig. 3 plotted from the expression (4) at $K_1 = 0{,}042$, $K_2 = 6{,}111 \cdot 10^5$ is marked off, as well as the curve A of the Fig. 1 for textured electric steel, on the characteristic areas. On the basic of parameters of this curve, as a solution of iterative methods values of the magnetic field strength H_{mi} were selected: $H_{m1} = 400$ A/m; H_{m2}=620 A/m; H_{m3}=830 A/m, H_{m4}=1350 A/m, H_{m5}=2500 A/m. Accordingly, by the set amplitude values of the magnetic induction B_{mi} on BMC for isotropic steel B_{m1}=0,271 T; B_{m2}=0,599 T; B_{m3}=1,251 T; B_{m4}=1,650 T; B_{m5}=1,690 T were determined. As an initial approximation of the method the same value of a magnetic field strength H_n=18,75 A/m, as for anisotropic steel was chosen. Results of examinations are presented in a Fig. 4 (a, b, c, d, e) from which it is evident, as in case of isotropic steel the method of parabolas (curves 4), as a whole, is the most effective for setting the required amplitude value of a magnetic induction B_m.

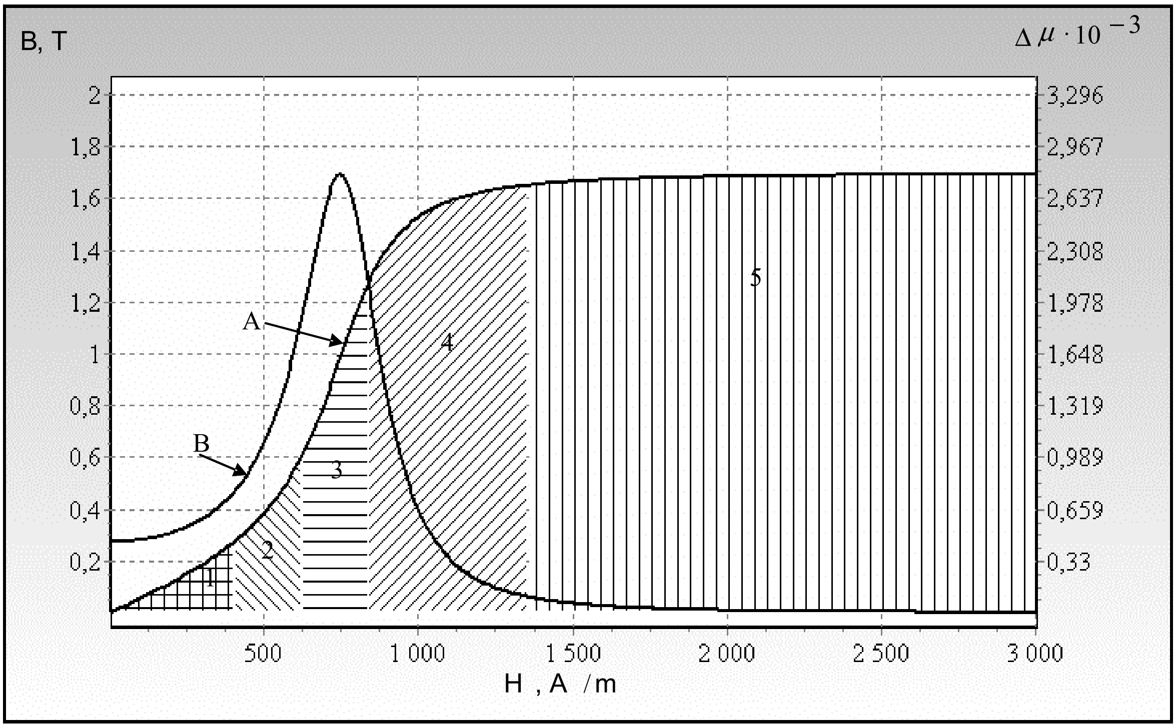

Fig. 3 – The basic magnetization curve (A) and a dependency of the relative differential magnetic permeability of isotropic electrical steel on a magnetic field strength (B).

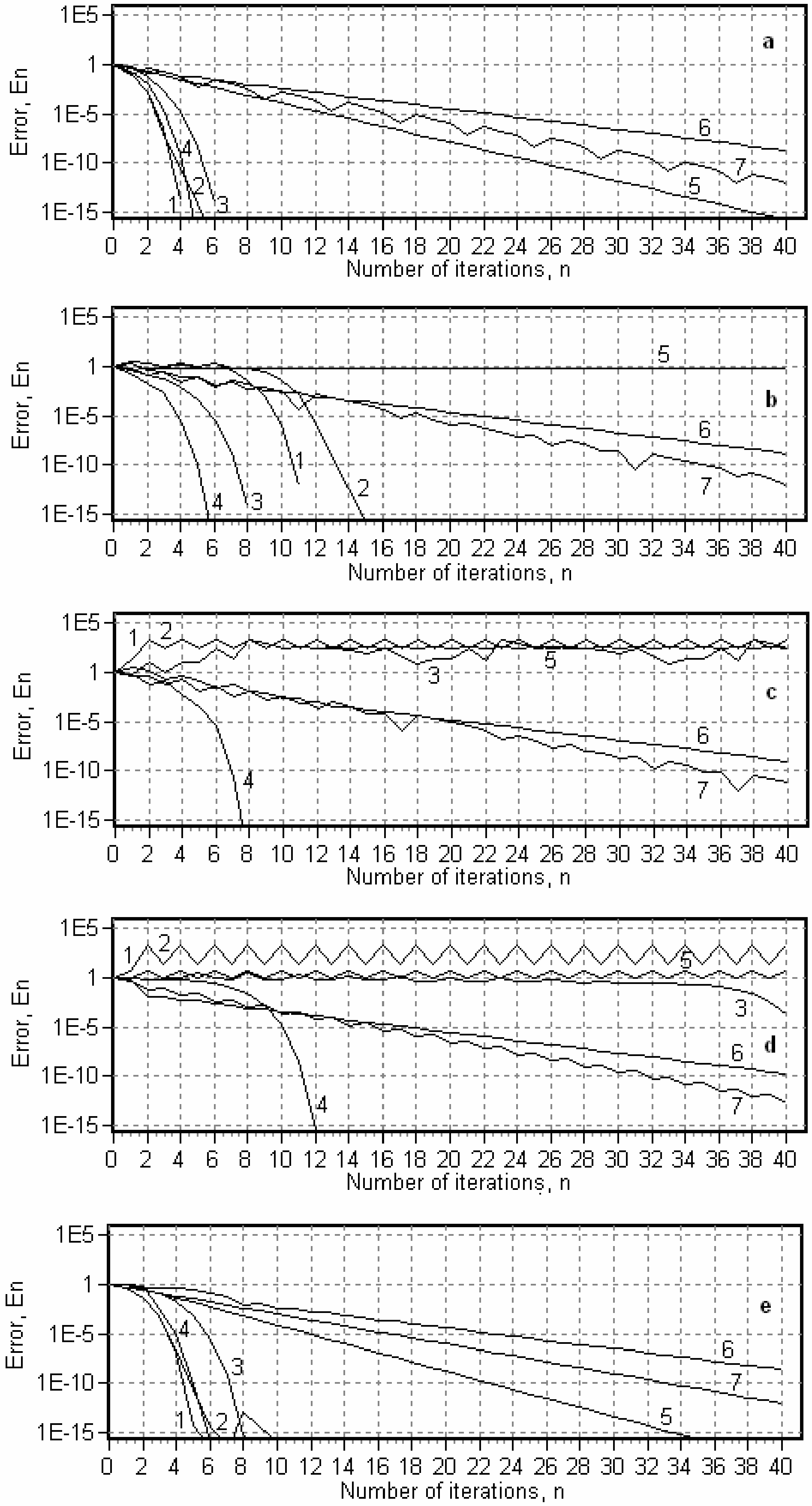

Fig. 4 – Character of behaviour of iterative methods setting amplitude values B_m of a magnetic induction in isotropic electric steel: a – $B_m = 0{,}271$ T; b – $B_m = 0{,}599$ T; c– $B_m = 1{,}251$ T; d – $B_m = 1{,}650$ T; e – $B_m = 1{,}690$ T.

3. Conclusions

For automatic setting of required amplitude values of the magnetic induction B_m at trials of a wide class electrical steels - as isotropic, and anisotropic, the rather effective iterative method is the method of parabolas. In this case, as initial approximation in an iterative process the value of a magnetic field strength in the beginning of a magnetization curve of tested material can be picked for all cases.

References

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