

# Determination of error measurement by means of the basic magnetization curve

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**Abstract.** The article describes the implementation of the methodology for determining the error search by means of the basic magnetization curve of electric cutting machines. The basic magnetization curve of the integrated operation of the electric characteristic allows one to define a fault type. In the process of measurement the definition of error calculation of the basic magnetization curve plays a major role as in accuracies of a particular characteristic can have a deleterious effect.

## 1. Introduction

In the course of the machine tools operation there arises a problem to make these machines available for the self-test drives. For example, to assess the extent of the drive failure we propose using a basic magnetization curve [3-5, 9] as an indication. A method for determination of the basic magnetization curve is based on the solution of the inverse problem of harmonic balance [1] by the natural-model tests [2, 6-8, 10]. An important role in the implementation of the method belongs to the error identification between the model and analyzed characteristics.

## 2. Materials and methods

All electric machine tools (solenoids, solenoid relays, motors) are movable and fixed parts are represented by the core and at least one working coil. During the operation of electric machine tools the current flows in the work coil, thus generating a working magnetic flux in the stationary part of the magnetic circuit that drives the movable part. The magnetic flux is determined by the design, the mutual arrangement of the working parts of the magnetic core and the coil, as well as the number of turns in it and the magnitude of the flowing current. During the working cycle of the movable part it moves relative to the fixed magnetic circuit, which also leads to a change in the magnetic flux. This suggests that the integral characteristic contains not only information about the operating parameters of the electric machine tools, but it also influences the quality of individual parts of the basic magnetization curve.

For the basic magnetization curve of electric machine tools it is necessary to work on the external changing magnetic field and to measure magnetic flux density occurring in the cross-section of the special sensor. To measure the basic magnetization curve of an electric machine tool we have tested assembled electric machine tools, which made it impossible to use the sensors of magnetic induction.

The method of determining the basic magnetization curve of electromagnets is an inversion harmonic balance method of natural-model tests [2, 6-8, 10], unifying the dimension of the physical



object and modeling of the object. The solution of the inverse problem of harmonic balance and the method of natural-model tests allow obtaining the basic magnetization curve, in which it is possible not only to determine the state of the electromagnet, but also the type of the fault. The technique is based on the previously conducted studies on obtainment of the basic magnetization curve of a fixed part of the magnetic circuit. The advantage of the proposed method is an opportunity to conduct a diagnosis in the course of an operational procedure and production. The method provides the basic magnetization curve of the operating cycle with the electromagnets error not exceeding 3 %.

Let us search the basic magnetization curve of the approximated electromagnet using the following expression:

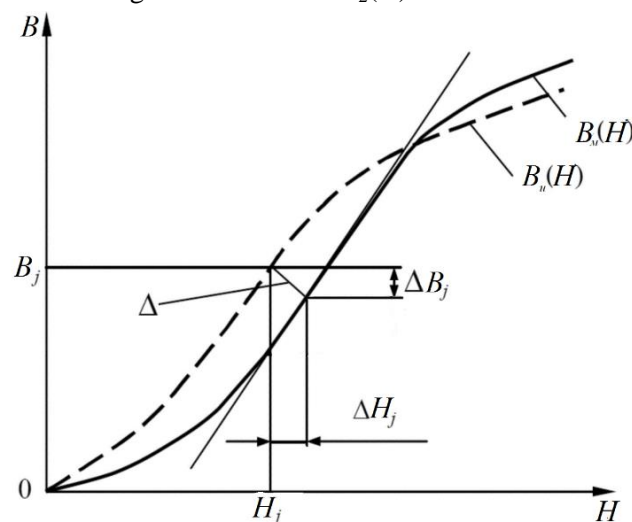
$$B = \sum_{m=1}^n k_{(2m-1)} H^{2m-1}$$

where  $B$  – a value of magnetic induction,  $k_{(2m-1)}$  – coefficients of the approximated basic magnetization curve,  $m = \overline{1, n}$ ,  $n$  – the number of conditions in the approximated curve,  $i$  – the current flowing through the coil of the electromagnet,  $H$  – magnetic intensity.

In our case, there is an electromagnet with the unknown basic magnetization curve; the known laws of variation of voltage are applied to the electromagnet, as well as to the current flowing through it. It is required to determine the coefficients  $k_{(2m-1)}$  expression approximating the basic magnetization curve.

In the experiments with electrical devices without moving parts of the magnetic circuit, which are used as a method to determine the basic magnetization curve of the electrical device, we used an algorithm of the natural-model test, which consists in the following: an electrical unit is supplied with sinusoidal voltage measured by current and voltage sensors, the input (voltage) and the output (current) are measured by an electrical signaling device, then the obtained data are sent to a personal computer, where model inputs are set to obtain the output data model using an optimization algorithm for search, which matches the output of the electrical device and its model. The simplex method of optimization was used as a basis for constructing an optimization algorithm of the control program. The program implements an electromagnet, and an optimization program based on simplex-planning.

The method of finding errors between the basic magnetization curves is explained in Figure 1. On exemplary basic magnetization curve  $B_1(H)$  we set points which are arranged perpendicular to the intersection with measured basic magnetization curve  $B_2(H)$ .



**Figure 1.** Explanation of the method of finding errors.

The absolute error of magnetic induction  $B$  and magnetic intensity  $H$  at each test point is determined as the projection pieces made between the model and measured characteristics  $\Delta B$  and  $\Delta H$

on the coordinate axis. The relative error of  $B$  and  $H$ , as well as complete measurement error characteristics are determined by expressions:

$$\delta_H = \frac{\Delta H}{H}, \quad \delta_B = \frac{\Delta B}{B}, \quad \delta = \sqrt{\delta_H^2 + \delta_B^2}.$$

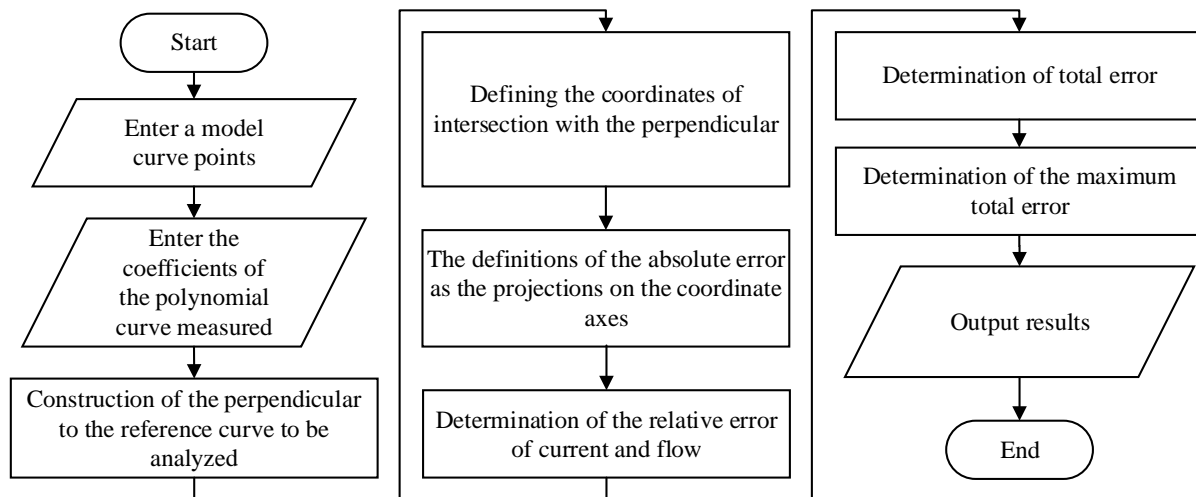
From the obtained results and the selected maximum we take the basic magnetization curve as a measurement error.

### 3. Results

The program implements the described technique. In this program a model of the basic magnetization curves defined by points and measured in the form of a polynomial of an odd degree:

$$B = \sum_{i=1}^n k_{2n-1} H^{2n-1}.$$

A diagram of the program is shown in Figure 2.



**Figure 2.** An algorithm for the program.

The algorithm operates as it is shown. The initial data provide an exemplary basic magnetization curve in the form of two column vectors and a measured basic magnetization curve in the form of a polynomial of an odd degree. Let us calculate the equation of the line passing through an  $i$ -point, wherein the calculated error and the  $(i + 1)$  point inside are

$$y_i = kx_i + b.$$

Then we shall calculate the equation of the perpendicular to this line in the  $i$ -point inside

$$y_{i+1} - y_i = -\frac{1}{k}(x_{i+1} - x_i).$$

We seek a point of intersection of the perpendicular and the measured basic magnetization curve given in the form of the polynomial. Knowing the coordinates of the intersection of the perpendicular model and measured characteristics, the determined projection on the coordinate axes (current and flux) is an absolute error:

$$\Delta_{Hi} = x_{oi} - x_{ai}; \quad \Delta_{Bi} = y_{oi} - y_{ai},$$

where  $x_{oi}$  and  $y_{oi}$  are points on the exemplary characteristic, and  $x_{ai}$  and  $y_{ai}$  are points on the measured characteristic. The relative error can be found by dividing the length of the projection on the coordinate axes and coordinate values corresponding to the  $i$ -point:

$$\delta_{Hi} = \frac{\Delta_{Hi}}{x_{oi}}, \quad \delta_{Bi} = \frac{\Delta_{Bi}}{y_{oi}}.$$

Further, the total error calculated in the  $i$ -point is

$$\delta_i = \sqrt{\delta_{Ht}^2 + \delta_{Bt}^2}.$$

After calculation of errors at all points let us find the maximum value, which is an error between the model and the analyzed basic magnetization curve:

$$jj := \begin{bmatrix} j_1 \\ j_2 \\ j_3 \\ j_4 \\ j_5 \\ j_6 \\ j_7 \\ j_8 \\ j_9 \\ j_{10} \end{bmatrix}; ff := \begin{bmatrix} f_1 \\ f_2 \\ f_3 \\ f_4 \\ f_5 \\ f_6 \\ f_7 \\ f_8 \\ f_9 \\ f_{10} \end{bmatrix}$$

$$k_1 := k_1; k_3 := k_3; k_5 := k_5; k_7 := k_7; k_9 := k_9$$

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for i from 1 to 9 by 1 do y0i := y2p; x0i := x2p; ci := solve({y1i = ai·x1i + bp, y2i = ai·x2i + bi},
  {ap, bi}); ai := solve(ci[1], ai); bi := solve(ci[2], bi); ni := yi = solve(yi - y0i = -1/ai (xi
  - x0i), yi); di := solve({np·yi = k1·xi1 + k3·xi3 + k5·xi5 + k7·xi7 + k9·xi9}, {xp, yi}); xxi
  := di[1]; xxxi := solve(xxi[1], xi); yyyi := solve(xxi[2], yi); pxi := abs(xxxi - x0i)
  / x0i
  ·100; pyi := abs(yyyi - y0i) / y0i ·100 od

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for i from 1 to 9 by 1 do y1i := jj[i]; y2i := jj[i + 1]; x1i := ff[i]; x2i := ff[i + 1] od

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pxx := convert(px, array)

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pyy := convert(py, array)

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For i from 1 to 9 by 1 do pz[i] := sqrt(pxx[i]2 + pyy[i]2) od

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pzmax := max(pz)

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print(pzmax)

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**Figure 2.** Listing of the error search program to analyze the basic magnetization curve.

In addition to this kind of the error, the method must take into account the error of the measurement device. Calculation of the error is reduced to the estimation of the standard deviation of individual links ( $\sigma_i$ ) taking into account additional errors from influencing factors and finding the total error of the measurement conversion:

$$\sigma_m = \sqrt{\sum \sigma_i^2}$$

The relative error in the measurement and a processing unit, reduced to the top of the measuring range is  $\delta_{ms} = 1\%$ , and reduced to the end –  $\delta_{me} = 2\%$ . The relative error of the shunt is  $\delta_{sh} = 0.5\%$ . The standard deviation of the error amplification unit consists of three components: a basic error (1%); pulsation error voltage (0.2%) and ambient temperature variations (0.66%). The error switch

consists of three components: an error voltage drop of a public key (0.4%), leakage current in each private key channel (0.13 %) and the carrier frequency ripple (0.06 %). ADC at the beginning and the end of a range is  $\delta_{ADCs} = 0.2 \%$  and  $\delta_{ADCe} = 0.3 \%$ .

1. We accept a value quintile ratio equal to  $k = 1.73$ . Based on a linear scale and formula  $\sigma_i = \frac{\delta_i}{k}$  we find  $\sigma_{ds} = 0.6 \%$ , and the end of the range, which is  $\sigma_{de} = 1.2 \%$ .

2. For shunt  $\delta_{shs} = \delta_{she} = 0.5 \%$ . Taking the above-mentioned conditions into account, we obtain  $\sigma_{shs} = \sigma_{she} = 0.29 \%$ .

3. We can obtain the block using  $\sigma = \sqrt{\sum \sigma_i^2} = \sqrt{1^2 + 0.2^2} = 1 \%$ .

Since the developed device has no other errors, the total error is  $\sigma_{dev} = \sqrt{\sum \sigma_i^2} = \sqrt{1^2 + 0.66^2} = 1.3 \%$ .

4. Let us switch, taking into account the conditions of point 1,

$$\sigma_s = \frac{1}{1.73} \sqrt{0.4^2 + 0.13^2 + 0.06^2} = 0.24 \%.$$

5. The relative error of the ADC set. Assuming the law of the uniform distribution, we obtain

$$\sigma_{ADCs} = \frac{0,2}{1.73} = 0.13\% \quad \sigma_{ADCe} = \frac{0,3}{1.73} = 0.17\%.$$

6. Finally, the standard deviation for the end of the range will be

$$\sigma_{sume} = \sqrt{1.1^2 + 0.39^2 + 1.3^2 + 0.24^2 + 0.13^2} = 1.76 \%,$$

and for the beginning of the measuring range it will be

$$\sigma_{sums} = \sqrt{0.6^2 + 0.39^2 + 1.3^2 + 0.24^2 + 0.17^2} = 1.5 \%.$$

## Conclusion

In the present paper we have developed an algorithm and a program that allows determining the location of the error of the basic magnetization curve of electric cutting machines.

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