Parameters for expressing an analytical magnetization curve obtained using a genetic algorithm

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***Abstract*—Measured magnetization curves are usually given as a table of magnetic field strength and magnetic flux density values. Some finite element methods' programs use analytical formulas for defining the magnetization curve. In this way the curve is more continuous and the calculation is more stable. It is difficult to correctly determine the parameters of analytical formulas as successfully as analytically calculated curves cover measured curves. We used a genetic algorithm for determining the analytic curve parameters for two curves used in Cedrat Flux, and the curve that we set ourselves.**

***Index Terms*—Magnetic fields, Genetic algorithms, Finite element methods.**

I. Introduction

In some cases it is better to use analytically written magnetization curves than to use magnetization curves written as a table of values. Analytical magnetization curves are more continuous and because of this the calculation procedure is more stable. The main problem is to define appropriate values for the analytical curves' parameters [1], [2], [3], [4], [5]. We decided to use a genetic algorithm [6].

II. Genetic algorithm used for the analytical curve's parameters definition

Genetic algorithms are used for solving many technical problems. They are stable, useful for solving problems with high numbers of unknowns, and are able to avoid local minimums etc [6]. The algorithm we used for determining the analytical curve's parameters is presented in Fig. 1.

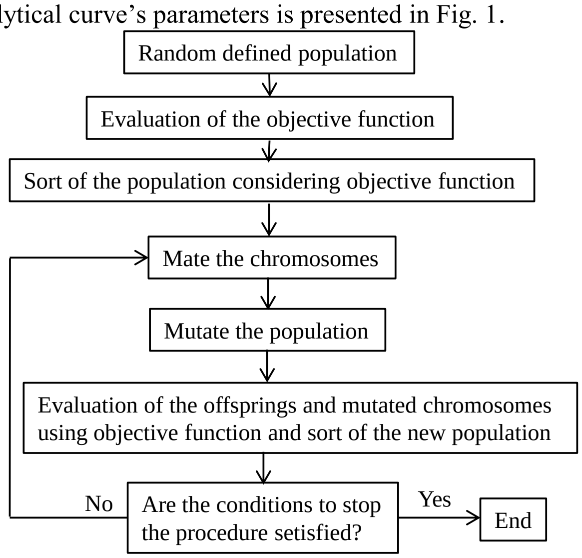

Fig. 1. Genetic algorithm

Objective function is defined with equation (1).

$$f = \frac{1}{n}\left(\sum_{i=1}^{n}\left|B_{\text{calculated\_i}} - B_{\text{measured\_i}}\right|\right) \tag{1}$$

$B_{\text{mesaured\_i}}$ are the measured values for the magnetization curve's magnetic flux density and $B_{\text{calculated\_i}}$ are the calculated values for the B obtained using analytical formula. n is the number of points defining the measured magnetization curve. The objective function's first part $1/n$ gives us the possibility of comparing the closeness of the analytical curve to the measured curve for those curves with different numbers of measured points. In the continuation, calculations with different analytical formulas are presented.

The better part of the population are kept and used for calculating new offspring and after iteration we keep 50% of the better population considering the objective function. Mutations are made using a random function but only part of the population is mutated. We mutated 20% of the population. Offsprings and mutated chromosomes are evaluated using the objective function and sorted considering evaluation.

Different conditions for finishing the procedure can be used. The final number of iterations can be set if we assume that after a sufficiently large number of iterations we have obtained the result. We can stop the iterative procedure if we know the value of the objective function that must be reached. This condition is difficult to set, because the value of the objective function that could be reached is different for different magnetization curves. We can also stop the iterative procedure if the minimum objective function remains the same after a large number of successive iterations.

III. Used analytical expressions

We calculated the parameters for three analytical formulas. The first formula is used for the curve called C1 and it has only two parameters. This formula is used in Flux software. C1 has parameters initial relative permeability μ_r and saturation magnetization J_s. It is written in (2).

$$B(H) = \mu_0 H + \frac{2J_s}{\pi}\operatorname{arctg}\left(\frac{\pi\left(\mu_r - 1\right)\mu_0 H}{2J_s}\right) \tag{2}$$

The second formula is used for the curve C2 and it has three parameters. This formula is also used in Flux software. C2 has parameters μ_r, J_s and knee adjusting coefficient a. It is written in (3). The third formula is used for the curve C3 and it is based on a combination of the exponential functions.

$$B(H)=\mu_0 H+J_s\,\frac{H_a+1-\sqrt{\left(H_a+1\right)^2-4H_a\left(1-a\right)}}{2\left(1-a\right)} \tag{3}$$

$$H_a=\mu_0 H\,\frac{\mu_r-1}{J_s}$$

It has nine parameters, but they can be determined by the use of the genetic algorithm. The formula is written in (4).

$$\begin{aligned} B(H)=&P_1\left(1-e^{-P_2H}\right)+P_3\left(1-e^{-P_4H}\right)+\\ &+P_5\left(1-e^{-P_6H}\right)+P_7\left(1-e^{-P_8H}\right)+P_9\mu_0 H \end{aligned} \tag{4}$$

IV. Calculated Examples

The measured magnetization curve with commercial code 9S20 was used for the calculations of analytical curves. These curves are presented in Fig. 2.

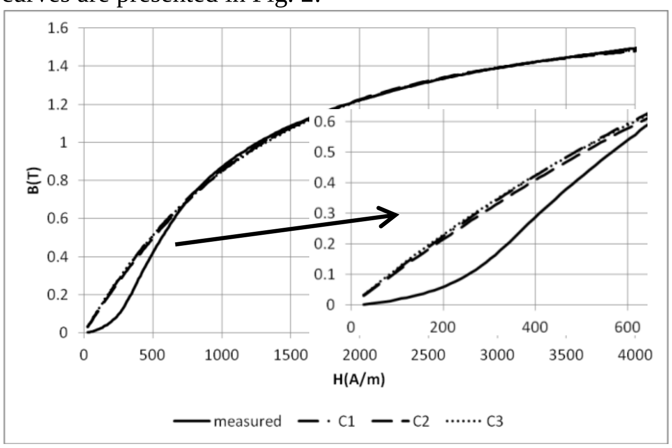

Fig. 2. Measured *B* and curves C1, C2 and C3 for the material 9S20.

For the curves shown in Fig. 2 the values of the objective function are *f*=0.026742 for C1, *f*=0.028841 for C2, and *f*=0.03196 for C3. The measured magnetization curve with commercial code EN300 was the second curve used for the calculation. These curves are shown in Fig. 3.

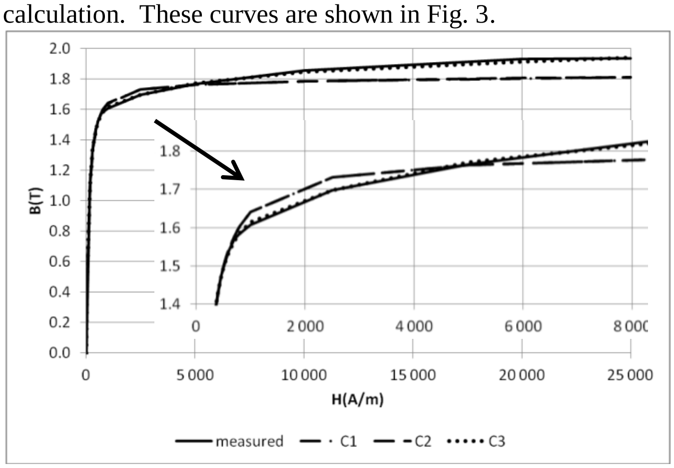

Fig. 3. Measured *B* and curves C1, C2 and C3 for the material EN300.

For the curves presented in Fig.3, the values of the objective function were *f*=0.034481 for C1, *f*=0.035041 for C2 and *f*=0.017597 for C3.

The objective function for the material EN300 for the calculation of nine parameters for curve C3 is shown in Fig. 4.

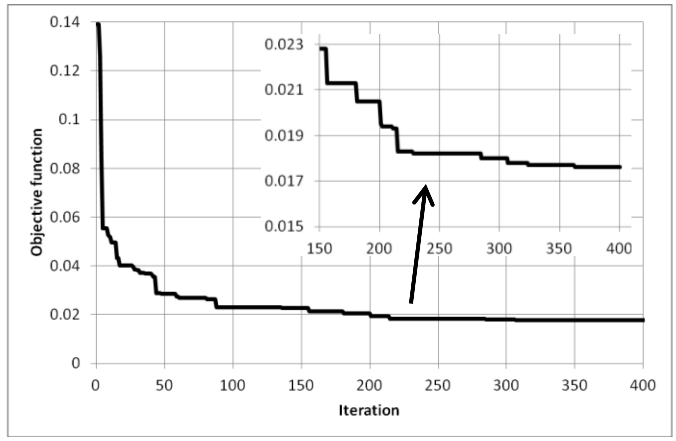

Fig. 4. Objective function for the curve C3and material EN300.

For the curve C1 we calculated two parameters and we used a population size of 20 members, for the curve C2 we used 30 members, and for the curve C3 we used 90 members.

From Fig. 4 we can see that the final result was obtained after 363 iterations. After that the best population member remained the same and we could stop the calculation procedure. The calculation procedure was not time-consuming even in the case of a larger number of points of the measured magnetization curve and also in the case of a larger number of genetic algorithm iterations.

V. Conclusions

The genetic algorithm is very useful for determining the coefficients of analytical curves. We do not need to look for the physical backgrounds of individual coefficients.

For the hard magnetic material 9S20, all three formulas gave us comparable results. From Fig. 3 we can see that all three formulas do not cover the measured curve exactly for *B* smaller than 0.6T. For the material EN300 with curve, which was extended within the saturation area, only curve C3 gave us appropriate results. From Fig. 3 we can see that curves C1 and C2 did not cover the measured curve within the area of the knee, and in the saturation area.

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