Parameterization of BH Curves
by Means of PSO

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Abstract

This work shows how from the point of view of optimization it is possible to find the values of constants that are part of the sum of exponentials that model the BH characteristic of the magnetization curves of some materials. The explanation of the general form of the PSO algorithm (Particle Swarm Optimization) with its respective flow chart and an example for the case of optimization with two variables is presented. Then we present the non-linear model of the BH curves and the motivation to use this model instead of others as the power series. Finally we have the formulation of the parameterization problem in an optimization problem to apply the PSO algorithm as a tool to minimize.
Keywords: BH curves, PSO algorithm, magnetization curves

1 Introduction

Particle Swarm Optimization (PSO) particle swarm optimization is an algorithm that solves the problem of finding the optimum value that maximizes or minimizes an objective function. The algorithm is widely used in applied engineering since it does not require the calculation of derivatives. This algorithm is based on the biological model of the organized behavior of large groups of animals such as flocks of birds, schools of fish or ant colonies. Each of the individuals that are part of the groups of animals mentioned above are known as particles, for the PSO algorithm, each particle has information of 4 characteristics [1]:

- Location (own) in the search space.
- The value of physical fitness. Whether or not the solution to the problem is better.
- Best personal location last.
- The best position, general position. The best location found by a particle of the swarm.

In the process of finding the solution there are no Gradients or Hessians to calculate. Each particle continuously adjusts its speed and trajectory in the search space based on the previous information, approaching the global optimum in each iteration. The behavior of PSO is modeled with the following equations:

\[ v_i^{k+1} = w_i v_i^k + c_1 Rand_1 (p Best_i - x_i^k) + c_2 Rand_2 (g Best_i - x_i^k) \]  \hspace{1cm} (1)

and

\[ x_i^{k+1} = x_i^k + v_i^{k+1} \]  \hspace{1cm} (2)

Here, \( w_i \) is the inertial factor of each particle. Momentum component of the speed. \( c_1, c_2 \) are positive constants, the acceleration coefficients. \( Rand_1 \) and \( Rand_2 \) random coefficients [01]. \( x_i \) i-th particle. \( p Best_i \) best previous position of the i-th particle. \( g Best \) better position of all the particles. \( v_i \) is the speed of the i-th particle. \( p Best_i - x_i^k \) represents the cognitive component of speed. \( (g Best - x_i^k) \) represents the social component of speed.
2 Representation of the characteristic curve of magnetization by means of sum of exponentials

There are many ways to characterize a set of points that represent the behavior of a function. Some of these techniques go through all the points of a curve but between sample and sample (point and point) there are too large oscillations if you want to use an interpolating polynomial. This problem can be avoided if the derivatives between sample and sample are known, which is difficult to calculate or quantify. Another way is to characterize the $BH$ curve by means of an exponential function of the form (3) as proposed in [2], but this representation is approximated in the linear zone and as the value of the magnetic flux density increases, the approach moves away from the points. On the other hand, it is possible to find a function $B(H)$ as the sum of exponentials of the form (4), which allows to find the characteristic curves of the magnetic materials with relatively low errors in the linear zone and in the non-linear curvature.

\[
B(H) = B_{max}(1 - e^{\alpha H}) \quad (3)
\]
\[
B(H) = a_0 + a_1e^{\alpha_1 H} + a_2e^{\alpha_2 H} + a_3e^{\alpha_3 H} + a_4e^{\alpha_4 H}. \quad (4)
\]

Eqs. (3) and (4) are non-linear which makes the search for the values of con and with them complex or even clear some variable of any of those functions. On the other hand, linearly approximate Eq.(4) is only possible if you want to work in a range of values (magnetic flux density), but what you are looking for are the values of y that best approximate the curve provided by the manufacturer as will be shown in the following sections. It is for these reasons that it is necessary to resort to some optimization technique that allows to work, model and apply non-linear equations and find a good approximation with a pre-established error [3]

3 Formulation optimization problem

The problem is to parameterize the curve of the magnetization characteristic of a magnetic material such as steel with ultra-low carbon alloy. This type of material is oriented type steels that offer lower losses in the core and higher permeability compared to other materials. They are used in the construction of transformers. For what to do the design engineer is important to know the behavior of these materials to select the best in terms of impurities, magnetic properties and efficiency [4]. On the other hand, drivers and transformers are
key components in modern power systems. In comparison with other passive
components, they are quite difficult to model for the following reasons:

- Magnetic components, especially transformers with multiple windings,
can have complex geometric structures. The flux in the magnetic core
can be divided into several paths with different magnetic properties. In
addition to the central flow, each coil has its own leakage flow.

- The main materials, such as iron alloy and ferrite, have a highly non-
linear behavior. At high flux densities, the core material becomes satu-
rated, which leads to a very low impedance of the inductor. In addition,
the effects of hysteresis and eddy currents cause frequency-dependent
losses.

Now, it is necessary to find the terms with and with which adjust the
samples of [4] to a curve with minimum error. To use the PSO algorithm, the
particles in the objective function must be evaluated, for this an optimization
problem must be considered according to the variables and the samples. For
the problem to be solved, the following objective function is proposed:

$$\min_{@(k)} \| Bm(k, H) - B \|^2 = \min_{@(k)} \| Bm(k, H_i) - B_i \|^2$$

Eq.(5) can be interpreted geometrically as the smallest distance between
the curve $Bm(k, H)$ and $B$. Since we want to minimize that distance, for each
of the $H_i$ samples we have their respective $Bm(k, H_i)$ images and there is a
vector of $k$ values that make that distance minimal. Given the samples of $B_i$
(output) and $H_i$ (input), it is possible to find values for $k$ (vector) in such a way
that it fits the data set of the $B$ vs $H$ curves provided by the manufacturers
[4]. By means of optimization techniques such as PSO, we find $k$ values that
minimize $F0$, that is, find the $k$ parameters that best fit $Bm$ to the curve
given by the manufacturers. The function that is found is valid for the domain
of $H$, but is even more adjusted in the linear part, where the transformers
work. Given some $k_0$ values for the variables $k$ that parametrize the non-linear
function $Bm(k, H)$, it is possible to find the $k$ values that minimize $F0$, that
is, solve the problem as an optimization problem. To obtain better results it
is possible to limit the answers with upper and lower limits [5].

4 Numerical results and discussion

The problem is to find the vector $k$ of variables with $a_i$ for $i = 0,1,\ldots,4$.
That is, the value of the variables that allow parameterizing the characteristic
$BH$ of the magnetization curve of steel with ultra-low carbon alloy. To apply
the PSO algorithm it is necessary to understand the parameterization problem
as an optimization problem. An objective function must be reached that is minimized, this implies finding the values of the $k$ vector that makes the curve optimal and that fits the samples of [4].

The ultra-low carbon alloy steel is used for the construction of transformers since it presents low losses in the core. The graph of Figure 1 shows the minimum value that objective function (5) takes, $fval = 0.008$ is the minimum value that optimizes Eq.(5) for optimal $k$ values.

The red line in Figure 2 is the curve that best fits the blue curve provided by the manufacturer. For low magnetic flux density values (Linear zone, $H < 5000[A/m]$) there is an equal behavior in both curves.

For visualization purposes, it is plotted in Figure 3 with a logarithmic scale for the magnetic flux density axis. The minimum value in both curves is clear that it does not coincide, but this is due to the error pre-established in the PSO algorithm to find an optimal response. In the iteration $n = 50$ there is a curve like the one in Figure 4 which tends to approach the curve of blue color, that is, the algorithm approaches the optimal value of the vector $k$. 

Figure 1: Best value FO.
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Figure 4: $B_{\text{approx}}_1$.

References


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