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Fitting Hysteresis Arctangent Model using Particle Swarm Optimization Method

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INTRODUCTION & AIM

The simulation of magnetic behaviour in materials requires a reliable, accurate and easy model to be implemented when, modelling electromagnetic devices. In literature, two major groups exist: the first is based on physical considerations [1] and the second presents mathematical laws that describe the form of the magnetic hysteresis curve [2]. Phenomenological models or mathematical models are characterized by simplicity of implementation; however, the physical ones are more complicated and need more time to be computed. Both models require knowledge of the parameters that define them.

In recent years, research on natural social behavior resulted in the creation of many swarm optimization algorithms capable of dealing with highly complicated optimization problems [3]. In this category one of the best known methods is the particle swarm optimization (PSO) [4].

This work suggests the use of PSO method in order to identify the parameters of the mathematical arctangent hysteresis model proposed in reference [2] and compare them with those obtained analytically by referring to an experimental hysteresis loop.

METHOD

Arctangent hysteresis model

For a given magnetic field H, the magnetic induction B in the arctangent model hysteresis curve is represented by the following equations:

For the upward curve: $$\mathrm{B} = a \arctan\big(b(\mathrm{H}-d)\big)c\mathrm{H}$$

For the downward curve: $$\mathrm{B} = a \arctan\big(b(\mathrm{H}+d)\big)c\mathrm{H}$$

The parameters a, b, c and d are analytically given from:

$$a = 2B_s/\pi$$
$$b = tan(\pi B_r/2B_s)/H_c$$
$$c = B_s - \Big((2/\pi)B_s arctan\big(b(H_s+H_c)\big)\Big)/H_s$$
$$d = H_c$$

The parameters Bs, Br, Hc and Hs are obtained from a measured B(H) curve.

Particle swarm optimization method

This method is based on the definition of a search space, which includes a set number of particles Ns and the function to be optimized. Each particle is identified by its present location, speed, and best its position. During the optimization procedure, each particle moved to obtain its optimum position according to the equations shown below:

$$x_i^{t+1} = x_i^t + v_i^{t+1} \quad , \qquad i = 1 \ldots N_s$$

Where x_i^{t+1} and x_i^t are respectively the position of the particle *i* at iteration *t+1* and iteration *t*. v_i^{t+1} is the velocity of a particle i at iteration *t+1*, it is given by the following expression:

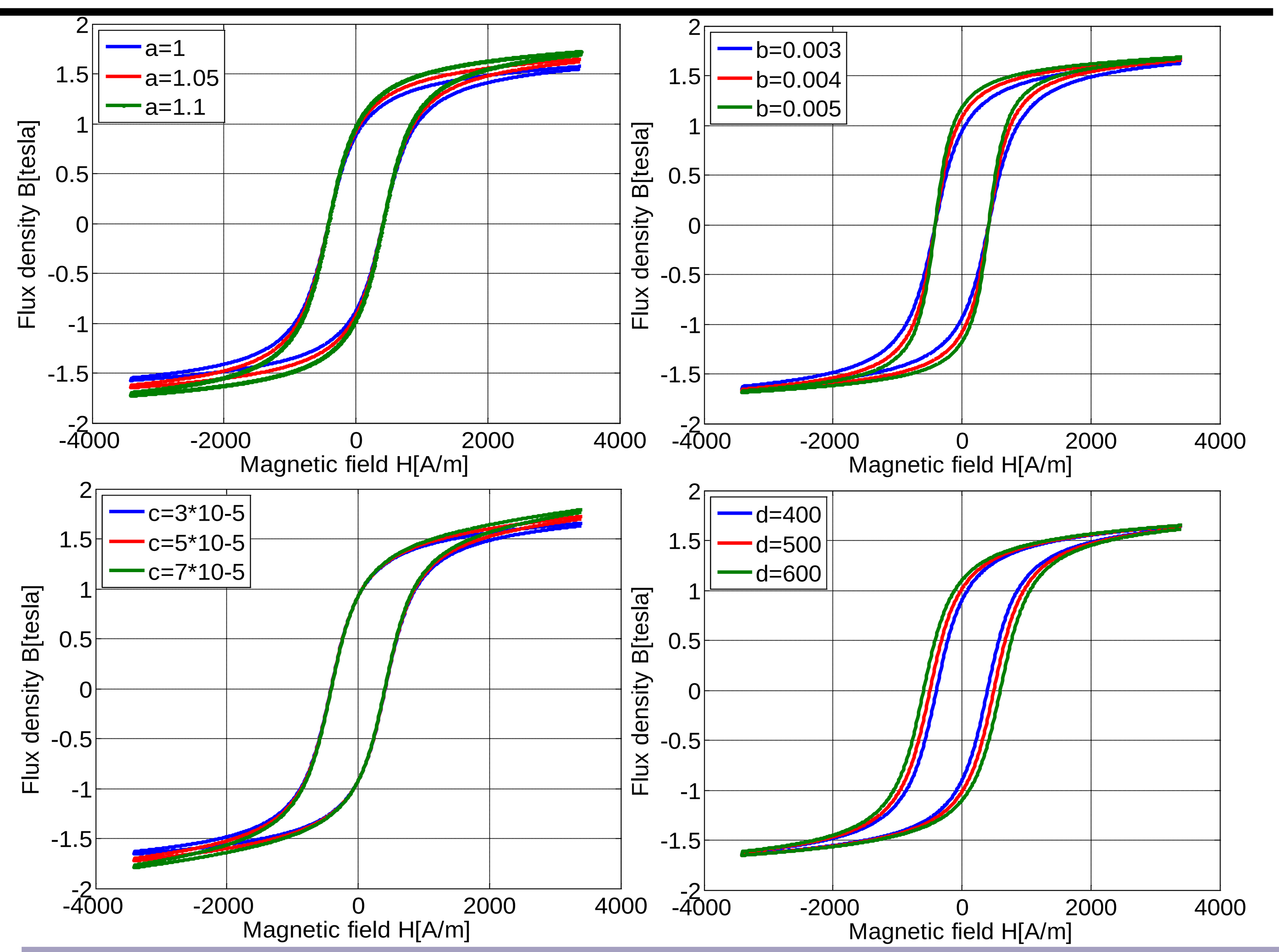
$$v_i^{t+1} = \omega v_i^t + \varphi_1 * r_1 * \left(pbest_i^t - x_i^t\right) + \varphi_2 * r_2 * \left(gbest_g^t - x_i^t\right), \quad i = 1 \ldots N_s$$

v_i^t is the current velocity of the particle *i*. φ_1 and φ_2 are the acceleration coefficients, r_1 and r_2 are random variables generated from a uniform distribution in the interval [0 1], $pbest_i^t$ is the own best position identified during the trajectory of the particle *i*, $gbest_g^t$ is the best global position in the entire swarm in each iteration. Finally, ω is an inertia weight.

RESULTS & DISCUSSION

Effect of the arctangent parameters on hysteresis shape

The study of the influence of the four parameters (a, b, c and d) on the hysteresis loop makes it possible to clearly specify which interval must be modified during the optimization process



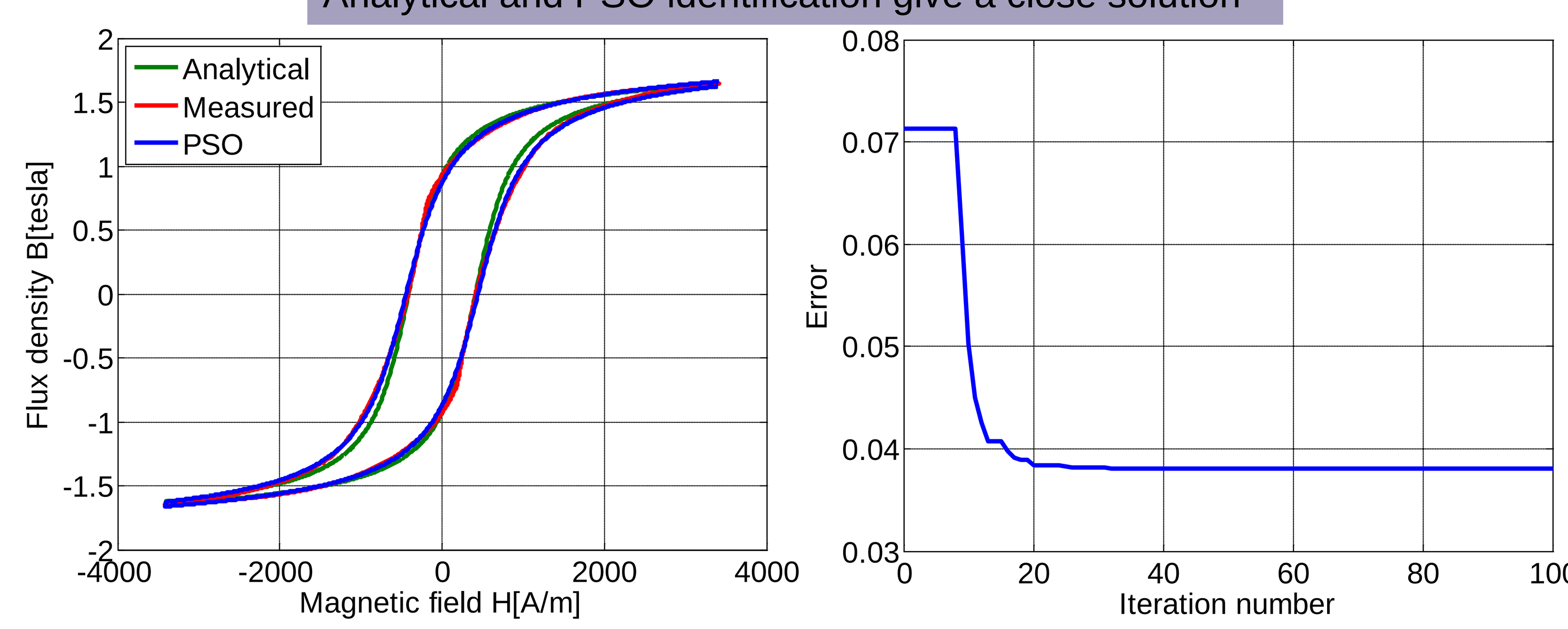
When parameter *a* increases the value of the saturation magnetic induction increases too, a significant change in the knee region of the hysteresis curve occurs with the increase of parameter *b*, a raise of parameter *c* reduces the slope of the hysteresis shape and coercitive field varies proportionally with the increase of parameter *d*.

Solution of optimization procedure

Table I. Analytical and optimized values

Parameters	Variable range	Analytical solution	PSO method
a	0 - 10	1.0504	1.0832
b	$1{\times}10^{-3}$ - $9{\times}10^{-3}$	0.0029	0.0023
c	$1{\times}10^{-5}$ - $4{\times}10^{-4}$	$2.7318{\times}10^{-5}$	$2.3696{\times}10^{-5}$
d	100 - 1000	418	447.7044

Analytical and PSO identification give a close solution



- The hysteresis curve generated by the parameters obtained from PSO method, leads to a better fit of the measured loop than those calculated using the analytical approach.
- The convergence of PSO method is very fast and can be reached in a few iterations.

CONCLUSION

The identification of the set of parameters (*a, b, c and d*) exhibits the accuracy of the solution found using the PSO approach. The analytical solution is useful because it gives a first approximation of the intervals for each parameter. This research allows the use of the arctangent model in finite element implementation, where it is preferable to use a very simple magnetic hysteresis model, in order to minimize the calculation time.

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