Chaotic Harmony Search Approach Applied to Jiles-Atherton Vector Hysteresis Parameters Estimation

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Abstract —In this paper, a chaotic HS (CHS) approach based on the chaotic Zaslavskii map is proposed and evaluated. The proposed CHS presents an efficient strategy to improve the search performance in preventing premature convergence to local minima when compared with the classical harmony search HS algorithm. Numerical comparisons with results using classical HS and genetic algorithms demonstrated that the performance of the CHS is promising in Jiles-Atherton vector hysteresis model parameters identification.

I. INTRODUCTION

Harmonic search (HS) algorithm [1] was developed in an analogy with music improvisation process where musicians in an ensemble continue to polish their pitches in order to obtain better harmony. Jazz improvisation seeks to find musically pleasing harmony similar to the optimum design process which seeks to find optimum solution. The pitch of each musical instrument determines the aesthetic quality, just as the objective function value is determined by the set of values assigned to each decision variable. The musician then tunes some of these notes to achieve a better harmony. This candidate solution is then checked whether it satisfies the objective function or not, similar to the process of finding out whether euphonic music is obtained or not [2].

In laminated magnetic cores when the flux rotates in the lamination plane, one observes an increase in the magnetic losses. The magnetization in these regions is very complex needing a vector model to analyse and predict its behaviour. The vector Jiles-Atherton (J-A) hysteresis model is broadly employed in rotational flux modelling [3]. The vector J-A model needs a set of five parameters for each space direction taken into account. As the problem is essentially nonlinear, optimization algorithms must be considered. The main contribution of the present paper is to develop a chaotic HS (CHS) approach to solve optimization problems. The case study validated in this paper was the parameter estimation of Jiles-Atherton vector hysteresis model. Furthermore, simulation results of a proposed CHS are compared with other optimization techniques.

II. FUNDAMENTALS OF HARMONY SEARCH ALGORITHM

In the HS algorithm, musical performances seek a perfect state of harmony determined by aesthetic estimation, as the optimization algorithms seek a best state (i.e. global optimum) determined by the objective function value. The optimization procedure of the HS algorithm can be synthesized in the following steps [4]:

Step 1. Initialize the optimization problem and HS algorithm parameters. First, the optimization problem is specified as follows:

$$\text{Minimize } f(x) \text{ subject to } x_i \in X_i, \quad i = 1,..., N$$

where $f(x)$ is the objective function, x is the set of each decision variable (x_i); X_i is the set of the possible range of values for each design variable (continuous design variables), that is, $x_{i,lower} \leq X_i \leq x_{i,upper}$, where $x_{i,lower}$ and $x_{i,upper}$ are the lower and upper bounds for each decision variable; and N is the number of design variables. In this context, the HS algorithm parameters that are required to solve the optimization problem are also specified in this step. The number of solution vectors in harmony memory (HMS) that is the size of the harmony memory matrix, harmony memory considering rate (HMCR), pitch adjusting rate (PAR), and the maximum number of searches (stopping criterion) are selected in this step. Here, HMCR and PAR are parameters that are used to improve the solution vector. Both are defined in *Step 3*.

Step 2. Initialize the harmony memory. The harmony memory (HM) is a memory location where all the solution vectors (sets of decision variables) are stored. The HM matrix, shown in Eq. (1), is filled with randomly generated solution vectors using uniform distribution, where

$$\text{HM} = \begin{bmatrix} x_1^1 & x_2^1 & \cdots & x_{N\text{-}1}^1 & x_N^1 \\ x_1^2 & x_2^2 & \cdots & x_{N\text{-}1}^2 & x_N^2 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ x_1^{\text{HMS-1}} & x_2^{\text{HMS-1}} & \cdots & x_{N-1}^{\text{HMS-1}} & x_N^{\text{HMS-1}} \\ x_1^{\text{HMS}} & x_2^{\text{HMS}} & \cdots & x_{N-1}^{\text{HMS}} & x_N^{\text{HMS}} \end{bmatrix}. \quad (1)$$

Step 3. Improvise a new harmony from the HM. A new harmony vector, $x' = (x_1', x_2',..., x_N')$, is generated based on three rules: i) memory consideration, ii) pitch adjustment, and iii) random selection. The generation of a new harmony is called 'improvisation'. In the memory consideration, the value of the first decision variable (x_1') for the new vector is chosen from any value in the specified HM range $\left(x_1' - x_1^{HMS}\right)$. Values of the other decision variables $(x_2',..., x_N')$ are chosen in the same manner. The HMCR, which varies between 0 and 1, is the rate of choosing one value from the historical values stored in the HM, while (1 -

HMCR) is the rate of randomly selecting one value from the possible range of values.

$$x_i' \leftarrow \begin{cases} x_i' \in \{x_i^1, x_i^2, \ldots, x_i^{HMS}\} & \text{with probability HMCR} \\ x_i' \in X_i & \text{with probability (1-HMCR).} \end{cases} \quad (2)$$

After, every component obtained by the memory consideration is examined to determine whether it should be pitch-adjusted. This operation uses the PAR parameter, which is the rate of pitch adjustment (PA) as follows:

$$\text{PA decision for } x_i' \leftarrow \begin{cases} \text{Yes} & \text{with probability PAR} \\ \text{No} & \text{with probability (1 - PAR).} \end{cases} \quad (3)$$

The value of (1 - PAR) sets the rate of doing nothing. If the pitch adjustment decision for x_i' is Yes, x_i' is replaced as follows:

$$x_i' \leftarrow x_i' \pm r \cdot bw, \quad (4)$$

where bw is an arbitrary distance bandwidth, r is a random number generated using uniform distribution between 0 and 1. In *Step 3*, HM consideration, pitch adjustment or random selection is applied to each variable of the new harmony vector in turn.

Step 4. Update the HM. If the new harmony vector, $x' = (x_1', x_2', \ldots, x_N')$ is better than the worst harmony in the HM, judged in terms of the objective function value, F, the new harmony is included in the HM and the existing worst harmony is excluded from the HM.

Step 5. Repeat *Steps 3* and *4* until the stopping criterion has been satisfied, usually a sufficiently good objective function or a maximum number of iterations (generations), t_{max}. Maximum number of iterations criterion is adopted in this work.

On the other hand, recently, the idea of using chaotic systems instead of random strategies has been noticed in several fields. With the easy implementation and special ability to avoid being trapped in local optimum, chaos and chaos-based searching algorithms can be a good alternative to maintain the search diversity in stochastic optimization procedures. The proposed CHS uses the chaotic Zaslavskii map [5] normalized in range [0,1] to generate the bw value in each iteration of CHS.

III. OPTIMIZATION RESULTS

The J-A model, in its 2D version, needs ten parameters for an anisotropic material: magnetization (M_S), a, α, tensor (c) and second rank symmetric tensor (k) for the transverse and rolling directions (details in [3]). Experimental data, obtained from a Rotational Single Sheet Tester (RSST) are used in the curve fitting. The MSE (Mean Squared Error) and loss error between calculated and measured curves must be minimized [6].

In this work, the total number of solution vectors in classical HS and CHS, i.e., the HMS was 15 and t_{max} = 1,000 generations. All tested HS approaches adopt 15,000 objective function evaluations in each run. Furthermore, the bw, HMCR and PAR were 0.01, 0.9 and 0.3, respectively, in tested HS and CHS approaches. In terms of genetic algorithm, the population size is 15 and the stopping criterion was 1,000 generations. GA was evaluated with crossover and mutation probabilities of 0.8 and 0.2, respectively, and roulette wheel selection.

Table I presents the simulation results of objective function F of best solution after 1,000 generations in 30 runs. A result with Boldface means the best value found in Table I. Fig. 1 showed measured and calculated curves with the best parameters set obtained using CHS.

TABLE I
SIMULATION RESULTS OF F FOR THE J-A MODEL

Optimization method	Objective function F of best solution after 1,000 generations in 30 runs			
	Max (Worst)	Mean	Min(Best)	Std. Dev.
classical HS	30472.61	14037.34	6281.91	6841.57
chaotic HS (CHS)	12590.99	**7793.38**	**3951.78**	2711.93
GA	25271.28	17912.29	12351.38	4029.21

The CHS found the best convergence (mean of F) of tested setups of classical HS and GA approaches and also the best design (F=3951.77) with error between experimental and calculated losses of 0.5849%.

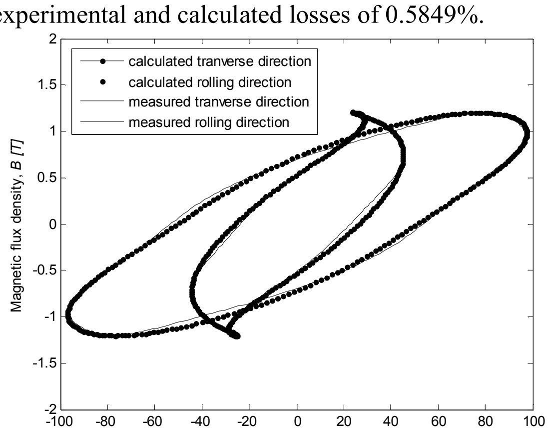

Figure 1. Calculated (best solution of CHS) and measured *B-H* curves for the material under rotational excitation.

Through the application of the proposed CHS was revealed promising to obtain an optimized parameters set for the vector Jiles-Atherton vector hysteresis model.

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