Distributed Cooperative Particle Swarm Optimization Algorithm for Optimization of Electromagnetic Mechanism

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Electromagnetic mechanism containing the permanent magnet is a common and typical electromagnetic mechanism that has advantages of low power consumption, small size, high sensitivity, and its optimization problem has aroused widespread concern. Calculation accuracy of electromagnetic properties and efficiency of optimization processes are two important factors that affect the optimization effect of electromagnetic mechanism. A fast calculation method was proposed in this study that aimed at permanent magnet electromagnetic mechanism's characteristics of strong non-linearity, low solving precision and hard convergence, zero-crossing of output characteristics and so forth. The response surface method was used to derive the basis function, and the error between measured values and calculated values was modified by the Kriging method. On the basis of the calculation model, the introduction of distributed collaborative strategy made the fast computation feasible. Simultaneously, the updating strategy of particles was improved, and robustness of the multi-objective particle swarm optimization algorithm(MOPSO) in solving the optimization problem of the permanent magnet electromagnetic mechanism was enhanced. Effectiveness of the method proposed in this paper was verified by the case study of a specific type of electromagnetic relay with permanent magnet.

***Index Terms* — Electromagnetic mechanism; Design optimization; Kriging; Response surface; Permanent magnet; MOPSO.**

I. INTRODUCTION

ELECTROMAGNETIC Mechanism is the most important component of electromechanical products such as electromagnetic relays, motors and electromagnetic actuators. Its work characteristics directly determine the performance and reliability of mechanical and electrical products and the entire electrical control system. Development goals of the electrical control system are miniaturization and low power consumption, which bring forward greater requirements on power, volume and sensitivity of electromagnetic mechanism. Additionally, application of the permanent magnet electromagnetic mechanism contributes to the solution of the above problems to a certain extent, and its design and optimization problems have attracted wide attention[1]-[4].

Taking full account that the Kriging method is suitable for calculating high nonlinear problems and the response surface method can directly reflect the functional relationship between input and output, this paper introduces actual measurement into approximate modeling, which solves the problems that the finite element calculation error is large and calculation of permanent magnet electromagnetic mechanism is inclined to non-convergence. Meanwhile, the multi-objective particle swarm optimization algorithm is improved, which consequently further improves the computational speed and convergence and realizes the multi-objective optimization design of electromagnetic mechanism.

II. THE OPTIMIZATION METHOD PROPOSED IN THIS PAPER

Latin hypercube design is applied within the tolerance range of the electromagnetic system parameters to generate sample points. Prototype model is used to obtain the output parameters, and the response surface method is used to obtain the mathematical relationships between various factors and output as the basis function of the approximate model. Calculated value of the basis function is different from the actual value. The difference between measured results and basis function results is taken as the interpolation node, and an error function is obtained by the Kriging method. The approximate model of electromagnetic mechanism composed of the basis function and the error function is shown in Equation 1.

$$y = K(x_1, x_2 ... x_n) + Z(x_1, x_2 ... x_n) \tag{1}$$

Establishment of the approximate model improves the computational accuracy and computational efficiency of the permanent magnet electromagnetic mechanism. Due to a large number of nonlinear factors, accomplishing a complete optimization still requires a mass of computer resources and time. Moreover, optimal design of electromagnetic mechanism requires multiple performance evaluations. In order to further increase the optimization efficiency, this paper improves the multi-objective particle swarm optimization method. The swarm size is set to $n_i = N / p$, where p is the number of sub-swarms that exchange information according to the von Neumann topology, and each sub-swarm is defined as a node. It should be noted that each node can only communicate with neighbor nodes, while information can be communicated throughout the whole topology.

III. CASE STUDY

A type of polarized electromagnetic relay with permanent magnet is selected as the research object in this paper, as shown in Fig.1.There are four key design parameters, which are width of left pole face, width of right pole face, thickness of magnetic steel and length of armature respectively. Original product parameters in this paper are as follows: F_1=5.3×10^{-6}N·m, F_2=2.809×10^{-6}N·m, F_3=1.468×10^{-6}N·m and F_4=7.190×10^{-6}N·m.

Firstly, the finite element method is carried out. It can be clearly seen from Fig.2 that there are large errors existing between the finite element calculation results and the measurement results at the end position, and the finite element calculation costs a long time. Therefore, it is unfeasible to optimize the permanent magnet electromagnetic mechanism by using the finite element method and finite element-based approximate model method. Output characteristics of each sample are measured by using the real prototype model, and a basis function is obtained by using the response surface method. Under the premise that the difference between exact values and values of the regression function model satisfies the white noise distribution, output characteristics of each sample are calculated by using the basis function. The difference between measured results and basis function results is taken as the interpolation node. Subsequently, the Kriging method is used to obtain the error function Z and the association function type displays as a Gaussian function. Fig.2 shows the comparison between measured results and results of the finite element method with voltage at 0V, 3V, 14V and 28V respectively. The comparison indicates that the results obtained in this paper are in good agreement with the measured. The max error does not exceed 3 × 10^{-8}N · m.

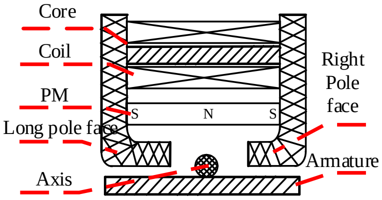

Fig.1.Electromagnetic mechanism with double permanent

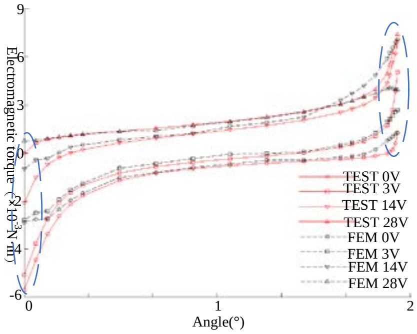

Fig.2. Comparison between measurement and finite element method

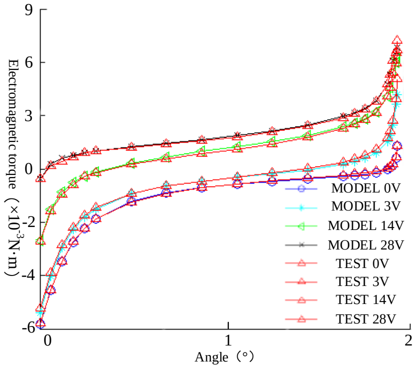

Fig.3.Comparison between measurement and approximate model

Output values corresponding to the original parameters are obtained through objective function model. The elite swarm of particles is gained via the multi-objective particle swarm optimization. Furthermore, particles whose four objective functions are superior to objective functions of the original product in the elite swarm are screened out, and non-dominated solutions therein are filtrated. Besides, Pareto solutions obtained are optimized with the above four objective functions. Then, the intersection is searched, to obtain the Pareto optimal solutions of the swarm. The randomness is reduced through optimizing for five times, and the final optimization results are consistent. Ultimately, a group of solutions is gained through optimization. Taking F_3 and F_4 as examples, it can be observed from Fig. 4 that compared with other algorithms, DCMOPSO algorithm of this paper possesses a stronger searching ability and a faster searching speed. In addition, optimal solutions searched are closer to the ideal Pareto and more extensively distributed.

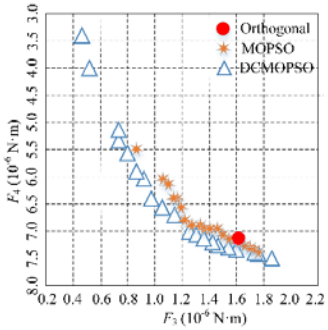

Fig. 4.Optimization results of various algorithms.

The output values gained via DCMOPSO are as follows: $F_1=5.32\times10^{-6}$N·m, $F_2=2.766\times10^{-6}$N·m, $F_3=1.845\times10$-6N·m and $F_4=7.587\times10^{-6}$N·m. The performance of F_1 is increased by 11.9%; the performance of F_2 is increased by 15.3%; the performance of F_3 is increased by 25.7%; and the performance of F_4 is increased by 5.52%. Such results are much better than the optimization results of orthogonal experiment.

IV. CONCLUSIONS

In this paper, the optimal model was obtained by introducing actual measured values into the approximate model. After that, the multi-objective optimization model was established, and its max error did not exceed 3×10^{-8}N·m. According to the comparison with other typical algorithms, electromagnetic attraction of the electromagnetic system is greatly increased, and the value of attractive force in the initial position under pull-in voltage is maximally increased by 25.7%, which proves that DCMOPSO in the multi-objective optimization of electromagnetic mechanism leads to efficient calculations and improved accuracy.

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