Optimization of Multi-objective Electromagnetic Device Based On Improved Artificial Searching Swarm Algorithm

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Artificial Searching Swarm Algorithm (ASSA) is a new bionic intelligent optimization algorithm and has been successfully applied in electrical fields. Multi-objective Optimization Problem (MOP) has become more and more important. Based on those discusses, this paper introduces the Pareto theory into the ASSA and proposes the Multi-objective Artificial Searching Swarm Algorithm (MOASSA). Three Multi-objective problems are selected to test the validity of MOASSA, and the experimental results verify the effectiveness of the proposed algorithm. After building optimization model, MOASSA has been successfully applied to solve the multi-objective optimization of double E-type AC contactor. The volume of electromagnetic system and the rated heat power have a significant reducing, which achieves energy saving and the reduction of material of the AC contactor.

***Key Words*— ASSA, Multi-objective optimization, Pareto theory, AC contactor**

I. Introduction

Artificial Searching Swarm Algorithm (ASSA) is a new bionic intelligent optimization algorithm, in this algorithm, the characteristics and process of a specific search tasks performed by human soldiers are simulated, the stipulated rules are executed to solve the corresponding optimization design problems. ASSA has been successfully applied in electromagnetic fields [1].

Multi-objective Optimization Problems (MOPs) are problems that consist of two or more objectives that have to be optimized simultaneously. When using an algorithm to deal with MOPs, the optimal solution is chosen from a set formed by a group of Pareto optimal solution called Pareto-optimal set. This paper introduces the Pareto theory into ASSA and proposes the Multi-objective Artificial Searching Swarm Algorithm (MOASSA).

Optimization design problems of electromagnetic devices have received wide concern, to deal with these problems from multi direction and multi angle attracts increasing attention recently. This paper uses MOASSA to optimize the double E-type AC contactor from two perspectives, and the expected results were achieved.

II. Artificial Search Swarm Algorithm And Its Improvement

A. Principle of Artificial Search Swarm Algorithm

ASSA simulates the process of the soldiers performing searching and investigative tasks. ASSA follows three behaviors: collaborative travel rules, investigative travel rules and random travel rules. According to the specific circumstances, the relevant behavior rule is selected by each search individual, thus with the development of iteration, the search target is gradually marched to by the search group, and the optimal object is approached or gotten, at the same time, the corresponding optimization problem can be solved .

B. Multi-objective artificial searching swarm algorithm

In this paper, based on the principle of Multi-objective Evolutionary Algorithm(MOEA) and Multi-objective Particle Swarm Optimization(MOPSO), the Pareto dominated theory is introduced into the algorithm, the out file storage mechanism is established and then the non dominated solutions which have been searched for are saved and outputted. The principle of density distance is used to maintain the out files and the global optimal value as well as the individual which sends out the call are selected from the out files, at the same time, the three behavior rules of ASSA are improved and the mutation operator is added in the algorithm, then the Multi-objective Artificial Searching Swarm Algorithm (MOASSA) is proposed finally.

The main operation of MOASSA is as follows: makeup the non dominated solution sets; maintain the out file set; select the global optimal value and individual optimal value; improve three behavior rules and design the mutation operator.

C. Performance test of MOASSA

TABLE I
TWO OBJECTIVES TEST FUNCTION

testing problem	value range	objective function $\min F(x)=\left(f_1(x), f_2(x)\right)$
SCH	$[-10^3,10^3]$	$f_1(x)=x^2$ $f_2(x)=(x-2)^2$
ZDT4	$x_1\in[0,1]$ $x_i\in[-5,5]$, $i=2,3,\cdots,n$	$f_1(x)=x_1$ $f_2(x)=g(x)\left[1-\sqrt{x_1/g(x)}\right]$ $g(x)=1+10(n-1)+\sum_{i=2}^{n}\left[x_i^2-10\cos(4\pi x_i)\right]$
ZDT6	$[0,1]$	$f_1(x)=1-\exp(-4x_1)\sin^6(6\pi x_1)$ $f_2(x)=g(x)\left[1-\left(f_1(x)/g(x)\right)^2\right]$ $g(x)=1+9\left[\left(\sum_{i=2}^{n}x_i/(n-1)\right)\right]^{0.25}$

To verify the validity of MOASSA, three test problems are chosen. Table I is part parameters of the test.

An approximate Pareto optimal obtained from the experiment of ZDT4 test function which carried out by MOASSA is shown in Fig.1.

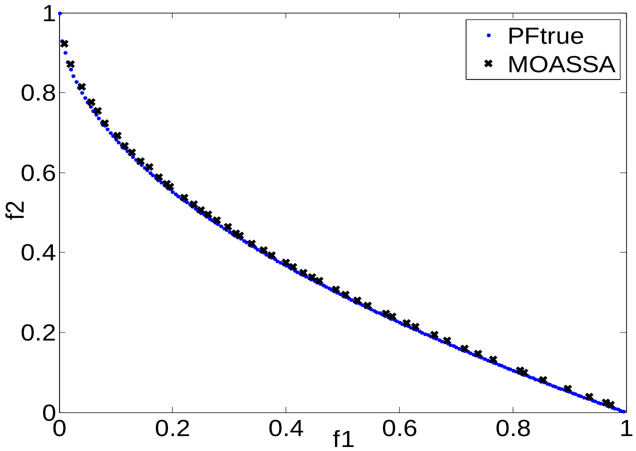

Fig. 1. Pareto front of test function ZDT4

The performance of MOASSA is exhibited by comparisons with several classical multi-objective optimization algorithms [2], such as Non-dominated Sorting Genetic Algorithm-II(NSGA-II), Strength Pareto Evolutionary Algorithm(SPEA-II) and Cloud Multi-objective Particle Swarm Optimization(CMOPSO). Part of the results is shown in Table II.

TABLE II
COMPARING RESULTS OF TWO OBJECTIVES TEST FUNCTION

test function	test index		NSGA-II	SPEA-II	MOASSA
ZDT6	GD	mean	9.2873e-02	8.1143e-02	2.427e-03
		variance	1.455e-03	1.624e-03	3.84e-04
	SP	mean	9.5491e-02	7.552e-03	1.996e-03
		variance	3.24e-04	4.37e-04	1.59e-04

In the ZDT6 issue, the results of MOASSA are better than that of Generational Distance(GD) and Spacing(SP).

III. Optimization Design Of AC Contactor

Some parameters that have great influence on the electromagnetic force are selected as optimization variables combined with the contactor of this paper.

$$X = [X_1,\ X_2,\ X_3,\ X_4,\ X_5,\ X_6]^T \quad (1)$$

X_1: the width of the middle magnetic pole; X_2: the width of the magnetic poles on both sides; X_3: the thickness of the magnetic pole; X_4: the width of the coil; X_5: the height of the coil; X_6: the distance between the poles.

This design takes the volume of the electromagnetic system and the rated heat power as the optimization targets, as in (2). Then optimize the targets under the constraint of suction force and temperature rise.

$$\begin{aligned} f_1(x) &= V_{Fe}(x) + V_{Cu}(x) \\ f_2(x) &= P(x) \\ \min F(x) &= \left(f_1(x), f_2(x) \right) \end{aligned} \quad (2)$$

The constraint of suction force and temperature rise are shown in (3) and (4).

$$F_{x\delta}(x)\big|_{U=U_R} - F_{f\delta} > 0 \quad (3)$$

$$\tau_m(x)\big|_{U=U_N} - \tau_0 < 0 \quad (4)$$

$F_{x\delta}(x)$ is the electromagnetic suction force, $F_{f\delta}$ is counterforce, δ is the work air gap, U_R is the reliable pull-in voltage, $\tau_m(x)$ is the working temperature rise of the coil under rated voltage, τ_0 is the temperature rise of the insulation allows.

In this paper, the optimization of AC contactor is a constrained multi-objective optimization, so the penalty function method is used to deal with the constraint condition. Equation (5) changes the objective function of penalty form to the unconstrained multi-objective optimization problem.

$$\begin{aligned} &\min F(x) = (f_1'(x), \dots, f_i'(x)) \\ &f_i'(x) = f_i(x) + \lambda R(x) \\ &R(x) = \sum_{j=1}^{m} \{\max(0, g_j(x))\}^2 \end{aligned} \quad (5)$$

In formula, $f_i'(x)$ is the ith objective function, $g_j(x)$ is the jth constraint function, λ is the penalty coefficient, R(x) is the constraint condition. The results are shown as table III.

TABLE III
OPTIMIZATION RESULTS

optimized parameters	Before optimization	After optimization
X1/mm	12.4	11.085
X2/mm	9.18	8.882
X3/mm	14.88	13.155
X4/mm	7	6.564
X5/mm	18.9	17.100
X6/mm	11.88	11.174
coil turns	5432	4602
the volume of iron/mm^3	21578.559	18907.241
the volume of copper/mm^3	12401.802	9686.347
rated power consumption /W	63.590	57.868

Adjust the coil turns properly, and check the constraint, the suction force is 6.56N, counter force is 2.42N, the temperature rise is 45.04°C, the temperature rise of the insulation permits is 50°C, all meet the conditions. It can be seen from the table that the volume of iron and copper is reduced obviously. The volume of iron is reduced by 12.3% and the volume of copper is reduced by about 21.8%. Power consumption has decreased meanwhile, energy saving 8.9%, the optimization effect is significant, and has a certain economic benefits.

References

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