Mass Ionized Particle Optimization Algorithm Applied to FEA based Optimal Design of Electric Machine

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An optimal design process of the electric machine is divided into optimization algorithm and characteristics analysis for calculation of objective function. The characteristic analysis of the electric machine is conducted primarily through Finite Element Analysis (FEA). Since FEA in electromagnetic analysis generally takes considerable computation time, it occupies most of convergence time in optimal design of electric machine. Thus, it is necessary to select appropriate optimization algorithm. In this paper, population based novel optimization algorithm is suggested named Mass Ionized Particle Optimization (MIPO). To prove the validity of MIPO, well-known test function like Branin function is adopted to compare the proposed algorithm and another population based algorithm, like PSO. In addition, the algorithm has been applied to optimal design for the torque ripple reduction of Interior Permanent Magnet Synchronous Machine.

***Index Terms*—Particle swarm optimization, electric machines, finite element analysis, design optimization**

I. Introduction

OPTIMAL DESIGN of electric machine is composed of characteristic analysis and optimization algorithm. Characteristic analysis is generally performed through Finite Element Analysis (FEA). Since FEA calls for considerable computation time, it is necessary to reduce computation time by selecting appropriate optimization algorithm [1].

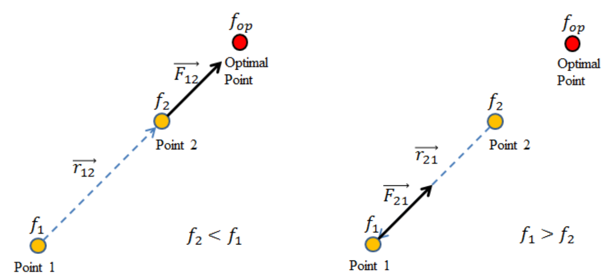
In this paper, a novel population based algorithm is suggested with the name of Mass Ionized Particle Optimization (MIPO), and its process is based on movement of positive or negative ionized particle. For the validation of MIPO, comparison with other population based algorithm such as PSO has been executed. The well-known test function like Branin function is adopted for validation. In addition, for the verification of MIPO, the algorithm is applied to optimal design of Interior Permanent Magnet Synchronous Machine (IPMSM) for its torque ripple reduction [2][3].

II. Mass Ionized Particle Optimization (MIPO) Algorithm

The MIPO is population based optimization algorithm that makes use of transition of randomly positioned N_s particles due to variations of their forces and masses affected by their relative distances and cost values. The basic characteristic of MIPO is that each particle has a certain mass which is inverse function of its cost value. In MIPO, for exploration of a particle positioned far from an optimum point and exploitation of a particle positioned close to an optimum point, the mass is defined to be bigger as particle approaches to the optimum point. In addition, since the net force on each particle should aim for optimum point, the particle that positioned relatively close to optimum point takes repulsion force from the particle positioned relatively far from optimum point. For the same reason, the particle positioned relatively far from optimum point takes gravity from the particle positioned relatively close to optimum point. The above rules define position of each particle at every generation[4].

For instance, as shown in Figs. 1(a) and (b), the force exchanged between point 1 and point 2 is defined as follow. The relation between cost value of point 1 and point 2 is $f_1 > f_2$.

$$\overrightarrow{F_{12}} = k\frac{\frac{(f_1-f_2)}{(\max(f_1,f_2)-f_{op})}}{\frac{l_b}{(l_b-|\overrightarrow{r_{12}}|)}}\widehat{r_{12}},\ \overrightarrow{F_{21}} = k\frac{\frac{(f_2-f_1)}{(\max(f_1,f_2)-f_{op})}}{\frac{l_b}{(l_b-|\overrightarrow{r_{21}}|)}}\widehat{r_{21}} \quad (1)$$



(a) Force at Point 2 by Point 1 (b) Force at Point 1 by Point 2

Fig. 1. Direction of force between Point 1 and Point 2

In equation (1), the proportion coefficient k is defined as $k = \frac{1}{n_{init}}$, and l_b is defined as

$$l_b = \sqrt[n]{a^2 + b^2 + c^2 + \cdots} \quad (2)$$

where a, b, c, ⋯ in equation (2) means search range of each dimension, and n means the number of dimension.

Consequently, the net force in a particle M is defined as sum of force from the other particles.

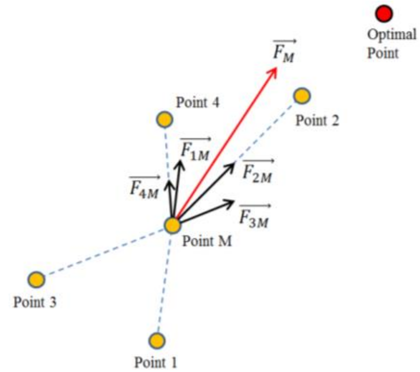


Fig. 2. Net force in particle M

The acceleration of particles in MIPO is defined from the Newton's second law. Thus, acceleration is defined by dividing the net force of the particle M by its mass such that

$$a_M = \frac{1}{m_M}\sum_{n=1}^{n_{init}} k \frac{\frac{(f_M - f_n)}{(\max(f_M,f_n)-f_{op})}}{\frac{(l_b)}{(l_b - |\overrightarrow{r_{1M}}|)}} \widehat{r_{1M}} \tag{3}$$

where m_M is defined as $m_M = \frac{\max(f_1,f_2,f_3,\cdots,f_{n_{init}})}{f_{n_{init}}}$. From Eq. (3), the position of particle in the next generation is

$$\mathbf{X}_M = \frac{1}{m_M}\sum_{n=1}^{n_{init}} k \frac{\frac{(f_1 - f_M)}{(\max(f_1,f_M)-f_{op})}}{\frac{(l_b)}{(l_b - |\overrightarrow{r_{1M}}|)}} \widehat{r_{1M}} \cdot t^2 \tag{4}$$

From the acceleration function of particle, the magnitude of acceleration should be satisfying the condition of $0 < a_M < 1$. In Eq. 4, the transition of particles is function of interval t. The transition size of particles should be modified compatible with every objective function by adjusting the interval t, since that the boundary length is different every optimization problem.

III. Optimal Design of IPMSM

The type of electric machine applied to optimal design in this study is IPMSM. Due to saliency, IPMSM has high power density but, for the same reason, has relatively high torque ripple. That is, it is indispensable design objective to reduce the torque ripple in optimal design of IPMSM [5][6].

Fig. 3 shows the drawing of IPMSM adopted for torque ripple reduction optimal design in this paper. The design parameters are indicated as x_1, x_2, x_3, x_4, and x_5.

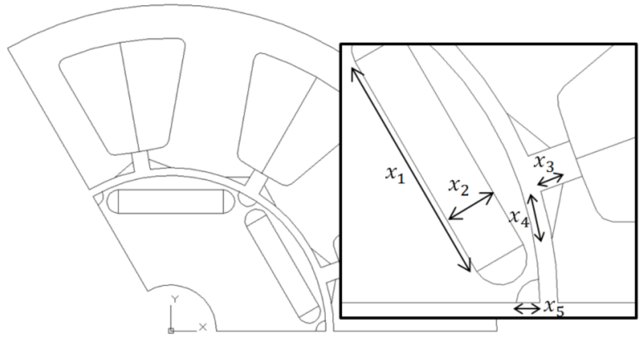
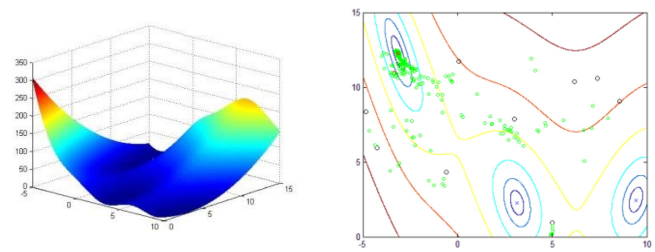


Fig. 3. Design parameter of IPMSM

IV. Numerical Validation

To prove validity of the proposed MIPO method, the well-known test function named Branin function is adopted. The shape of Branin function is shown in Fig. 4 (a) and result of convergence is shown in Fig. 4 (b).



(a) Branin function (b) Result of convergence

Fig. 4. Branin function and Result of convergence

The Branin function defined as below has 3 global minimum f(x1, x2)=0.3797887 in (-π, 12.275), (π, 2.275), (9.42478, 2.475), and its boundary is -5<x1<10, 0<x2<15.

$$f_{br}(x) = \left(x_2 - \frac{5.1}{4\pi^2}x_1^2 + \frac{5}{\pi}x_1 - 6\right)^2 + 10\left(1 - \frac{1}{8\pi}\right)\cos x_1 + 10 \tag{5}$$

Consequentially, MIPO shows less computation time than PSO when applied to Branin function. More detailed result for applying MIPO in optimal design of IPMSM will be dealt with in Full papar.

V. Conclusion

In this paper, a novel population based optimization algorithm named MIPO is proposed, and it is applied to optimal design of IPMSM for torque ripple reduction which has many local optima. For validity of proposed algorithm, comparison with PSO algorithm is executed and it shows less computation time.

VI. References

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