# A Robust Optimization Method using PSO with Multiple Finite Element Meshes for Minimizing Mesh Influence

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**An optimization method coupling an electromagnetic field simulation is widely employed for an electromagnetic device design. It is because an optimization method enables short development time and low material and development cost. A finite element method is often embedded with an optimization method. In finite element analysis, a simulation subject is subdivided into a mesh, and the accuracy of simulation is influenced by the mesh quality. Therefore, a solution obtained by the optimization method coupling the finite element method is also influenced by the mesh quality. In this paper, a modified PSO method is proposed to minimize the influence of the mesh quality. In the modified PSO method, multiple finite element meshes are employed, and the multiple optimal solutions are obtained. To decide a single final optimal solution from the multiple optima, a clustering technique is employed. To validate the proposed method, it is applied to an optimal design problem of a superconducting film magnetic shield for protecting a SQUID magnetometer and widening its effective area. By applying the proposed method, a realistic and expectable solution is obtained.**

***Index Terms*— Finite element mesh, optimization method, PSO, SQUID.**

## I. Introduction

In recent years, an optimization method coupling an electromagnetic field simulation is widely employed for design of an electromagnetic device. For instance, product apparatus are optimally designed, such as a motor [1], an inductor [2], *etc*. The reason why the optimization method is so widely used is short development time and low material and development cost.

A finite element method (FEM) is often embedded with an optimization method. For finite element analysis (FEA), it is necessary to subdivide a simulation subject into very small elements called mesh, and the mesh quality affects the accuracy of FEA. It is, however, well known that various meshes even with the same number of elements produce the FEA results of different accuracy. In designing a device shape using an optimization method with FEM, a mesh representing the subject shape is commonly generated by deformation of an initial mesh according to design variables. The quality of some deformed meshes may be deteriorated. The objective function values obtained by using such meshes are affected by their quality. For example, a computation accuracy of a motor torque ripple is strongly influenced by the mesh quality on the air gap [3], [4]. Since the mesh used in the optimal design process is automatically generated by deformation of an initial mesh, it is hard to achieve a highly accurate computation of the torque ripple for all the generated meshes. Based on these backgrounds, a shape optimization without influence of mesh quality is attempted in this paper.

The particle swarm optimization (PSO) method [5] is used as an optimization method in this paper. The proposed modified PSO method uses multiple different meshes to restrain the influence of the individual mesh. It is expected that the modification weakens the contribution of the individual mesh to the FEA accuracy in the optimization process.

For validating the proposed method, it is applied to an optimal design problem of a superconducting film magnetic shield for protecting a SQUID magnetometer and widening its effective area [6]. The purpose of the optimal design is to increase the effective area of the SQUID magnetometer. The SQUID magnetometer has a complicated shape, and the mesh quality affects the value of the objective function, so that it is suitable to apply the proposed method to the SQUID magnetometer design problem.

## II. Modified Particle Swarm Optimization Method

In the ordinary PSO method, every particle employs a common initial mesh. The mesh used in the optimization is automatically generated by deformation of the initial mesh. Fig. 1 shows deformation examples from initial meshes to automatically generated meshes.

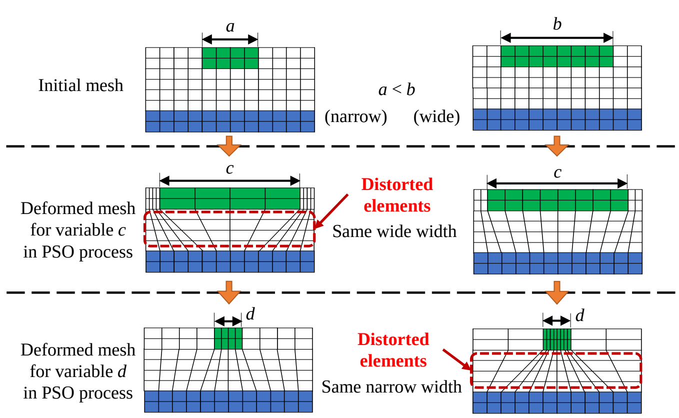
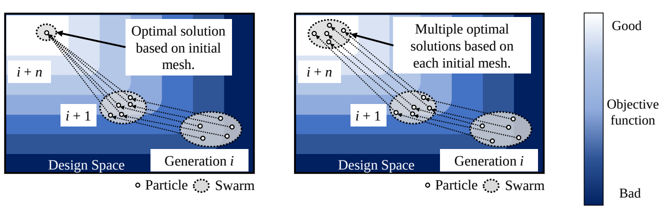



Fig. 1. Deformation of the initial mesh.

The distorted elements are generated according to the initial mesh and the design variable. The generated mesh influences the accuracy of the FEA result. Therefore, if the maximum value of the objective function was derived from the mesh of bad quality, it might not be an optimal solution. In addition, the meshes of bad quality might mislead the swarm toward a non-optimal solution. The initial mesh subconsciously affects the obtained optimization result.

In the proposed PSO method, the *i*-th particle moves toward its optimum with deformation of the *i*-th initial mesh as it is interacting with the others moving toward their own optima. Finally, *n* optima are obtained at maximum. After obtaining the multiple optima depending on the mesh difference, we can acquire an expectable solution among from them by excluding apparently incorrect solutions.

Fig. 2 shows the conceptual diagrams of the ordinary and the proposed PSO method. In Fig. 2(a), a single optimal solution is obtained by the ordinary PSO method because every particle uses one common initial mesh. However, the optimal solution may include a specific error stemmed from the initial mesh. On the other hand, the multiple optimal solutions are obtained in the proposed method as shown in Fig. 2(b), because every particle uses respective initial meshes. The proposed method similarly has a specific error on each optimal solution. However, it is expected that an optimal solution with apparent error, which is caused by the influence of an initial mesh, can be excluded. In the searching process, a particle affects the others and is affected by the others, so that the searching area moves toward the optimal solution with less specific error.




(a) ordinary PSO method. (b) proposed PSO method.
Fig. 2. Conceptual diagrams of (a) ordinary and (b) proposed method.

## III. SQUID AND OPTIMIZATION

For confirming the validity of the proposed method, it is applied to the optimal design problem of superconducting film magnetic-shield, which protects a SQUID magnetometer and enhances its effective area. The purpose of the optimal design problem is to increase the effective area of the SQUID magnetometer. Here, the objective function *F*, which represents the effective area of the SQUID magnetometer, is set as follows:

$$\text{maximize}\; F = A_{\text{eff}} = \Phi / B \tag{1}$$

where $A_{\text{eff}}$, $\Phi$, and $B$ are the effective area, the magnetic flux applying to the SQUID ring, and the external magnetic field, respectively.

The superconducting film magnetic shield, as shown in Fig. 3, covers the SQUID magnetometer, and its shape is a cross shape proposed in [6]. It protects the SQUID ring from a magnetic field and enhances the effective area of the SQUID ring. It is a several dozen μm away from the SQUID magnetometer. The design variables are the shield width and the air gap distance.

Fig. 4 shows all the exploration points during the optimization process, and the plots are colored by every particle. As shown in Fig. 4, all the profiles are similar, however the objective function values using Particle #1 are not correct in the case of wider shield than 0.6 mm, obviously.

Fig. 5 shows the plots of the highest five objective function values of every particle. The exploration points are distinguished into 6 clusters, as shown in Fig. 5. One cluster consists of a single exploration point and distant from the other clusters to the upper right. It is obvious that the distant cluster is inappropriate to the optimal solution, and it is deselected.

The detail of the determination way and another example will be described in the full paper due to lack of space.

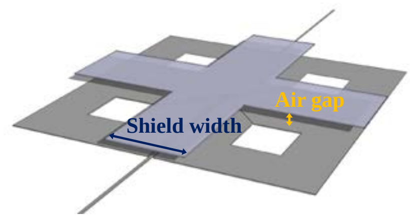



Fig. 3. Bird's eye view of SQUID magnetometer covered with cross-shaped superconducting film magnetic shield with design variables.

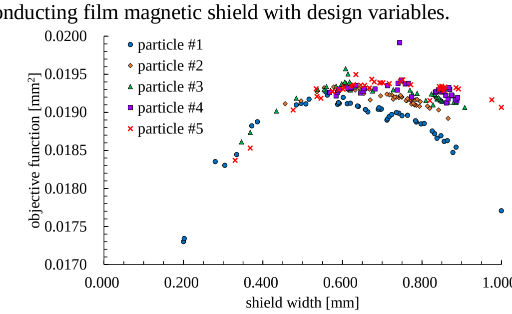



Fig. 4. Exploration points of every particle in the proposed PSO method. Plots are distinguished by color.

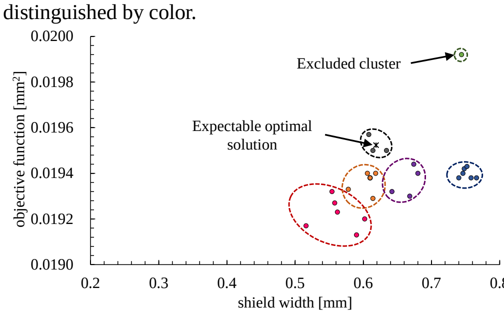



Fig. 5. Top five exploration points of every particle and clustering result by k-means algorithm.

## IV. REFERENCES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