Topology Optimization based on ON/OFF method with Surface Smoothing

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***Abstract*— A topology optimization method based on ON/OFF method and immune algorithm to obtain practical shapes is proposed. The topology optimization using evolutionary algorithms such as genetic algorithm often yields complex shapes which are impossible to produce in view of engineering. Moreover, lattice meshes which required in ON/OFF method result in poor ability of expression for curved surfaces. To solve these difficulties, filtering processes are introduced in the procedures of optimization. In particular, half material state in addition to ON/OFF states is introduced. The present method is applied to a shape optimization of shield model. The numerical results show that a feasible shape with double layer shield is obtained.**

***Index Terms*— Evolutionary algorithm, Finite element analysis, Topology optimization.**

I. Introduction

Topology optimization (TO) approach can obtain novel optimized shapes because this approach search the optimal shape by making free modifications in the distribution of material in contrast with parameter optimization[1]-[2]. The level set method is a typical approach to obtain optimal shape in TO [3]-[4]. In this method, the optimized shape is obtained by local search from initial shape using sensitivity analysis. Therefore, this approach often falls into local optima.

The ON/OFF method is another approach for TO [2],[5]. The authors have been proposed a TO method based on ON/OFF method with immune algorithm which is a kind of evolutionary algorithms [1]. The TO often yields significantly complicated shapes which are impossible to produce in view of engineering, because the TO allows larger number of degrees of freedom in the shapes and it is hard to include the engineering sense in the procedures of TO. To solve this difficulty, we have been introduced filtering processes [1]. This improvement successfully results in the practical optimized shapes [6]. In this method, lattice meshes (orthogonal grids) are required. This brings poor ability of expression for curved surfaces. The terraced surfaces deteriorate accuracy of FE analyses. In particular affect of this drawback appears in eddy current analysis because of skin effect. To solve these difficulties, half material state in addition to ON/OFF states is introduced. The half state elements are placed in curved surfaces so as to smooth the surface. The present method is applied to a shape optimization of shield model to show the effectiveness of the proposed smoothing process.

II. Present method

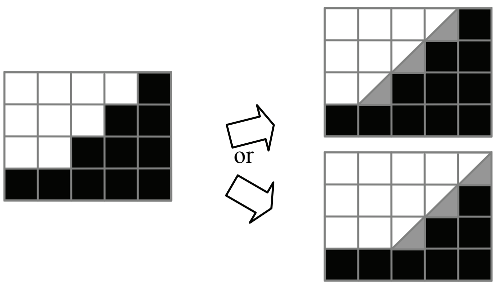
A. Immune algorithm

The immune algorithm for TO is inspired from the Clonal Selection Principle, and combines local and global search characteristics in order to avoid to fall into local optima. The ON/OFF method uses a 2D binary matrix for representing the material distribution in search region. The region is divided in a number of quadrilateral elements and each element has associated to it a binary value indicating either the presence or the absence of material. The procedures of the present method are summarized below.

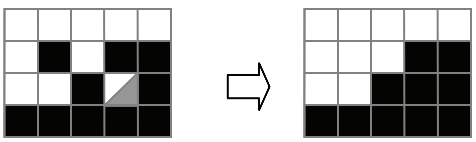
1. Generate an initial population of N random candidate solutions.
2. Evaluate the objective function for each antibody.
3. Test a stop criterion. If it is satisfied, stop the procedures.
4. Eliminate P [%] low-ranking antibodies.
5. Generate clones for each surviving antibodies. The highest-ranking antibodies receive a higher number of clones. The number of clones N_c^i for i-th ranking antibody is $N_c^i = \beta N / i$ where β is a constant.
6. Small-modifications on surface are applied to the clones, which are then evaluated over the objective function. Only the best candidate solution from each subset of (parent antibody + clones) is allowed to survive to the next generation.
7. Add randomly generated antibodies to replace the ones eliminated in Step 4, in order to keep the population size constant.
8. Back to step 2.

B. Filtering process

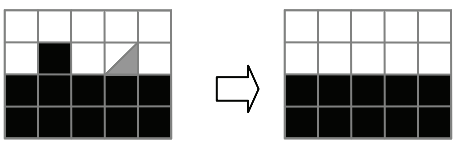
The present method adopts the following filtering process to obtain feasible optimal shapes. The *hole elimination* operator checks the neighborhood of all elements from the clone's distribution of material, and inverts the state of elements that present material boundaries at all four sides. The *surface smoothing* acts similarly to the hole elimination operator, but instead of acting in elements completely surrounded by different ones, it operates on both sides of the material boundary, checking for elements that present three boundary faces. In this work, the half state in addition to ON/OFF sates is introduced. The curved surface is filled with the half material in order to smooth the surface. Fig. 1 (a) illustrates an example of half material. The above mentioned hole elimination and surface smoothing operations are modified so as to meet the introducing of half material (see Fig. 1 (b), (c)). In step 6 of TO procedures, the small modifications are applied to clones. This operation has a role of local search. The state of material in randomly selected surface elements is reversed for this purpose.



(a) Half material



(b) Hole elimination



(c) Surface smoothing

Fig. 1 An example of half material

III. Numerical examples

We have performed an optimization of shape of shield shown in Fig. 2 to reduce the magnetic flux $\boldsymbol{B}$ in the evaluate region. A linear magnetic material with relative permeability μ_r = 200 is distributed on 30×30 grids placed in the design region. Each square grid is divided into 4 triangle elements so as to express the half material and the triangle elements are used as mesh for finite element analysis. The objective function f to minimize is defined as,

$$f = avg\,|\boldsymbol{B}|\,/\,|\boldsymbol{B}|_{ref} + S_{\mathrm{iron}} / S_{\mathrm{all}} \quad (1)$$

Where $avg|\boldsymbol{B}|$ denote the average of $\boldsymbol{B}$ in the evaluate region, $|\boldsymbol{B}|_{\mathrm{ref}}$ is average of $\boldsymbol{B}$ in a reference model consists of an inverted L-shaped shield and its value is 8.72×10^{-4} (T). S_{iron} and S_{all} are the area of magnetic material and the design region, respectively. The evolutional loops of TO procedures are iterated over 300th generation.

The initial distribution shown in Fig. 3 (a) is randomly generated. Thus the shape is considerably complex. The optimized distributions of materials obtained by the TO with N = 5, β = 3, P = 20% are shown in Fig.3 (b). The optimal shape obtained by the present TO method with filtering seems to be feasible. Moreover, we can see that a double layer shield clearly appears. Rough surfaces can be seen because of disable of surface smoothing. If it is applied to the optimized shape, smooth surface can be obtained though the value of objective function becomes somewhat poor.

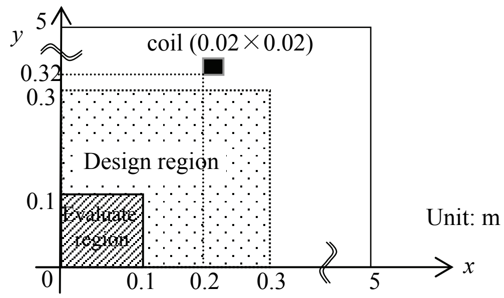
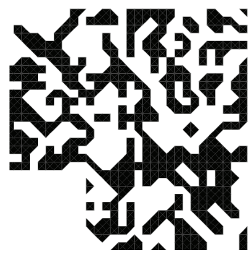
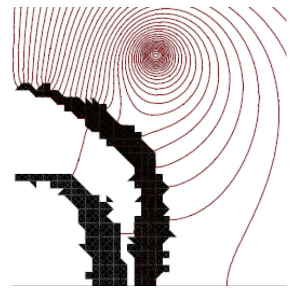


Fig. 2 shield model for topology optimization



(a) Initial distribution



(b) Optimized shape with flux line, f = 0.321

Fig. 3 initial and optimized distribution of material.

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