Optimal Design Method Based on Magnetic Material Distributions Using Multi Step Genetic Algorithm with Reduced Design Space

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Abstract — Topology optimization with material ON-OFF information in an element is one of the most attractive tools in initial conceptual and practical design of electrical machinery for engineers. Heuristic algorithms based on random search allow the engineers to define the general-purpose objective function, however, there are many iterations of finite element analysis, and it is difficult to realize the practical solution without island and void distribution. This paper presents the topological optimal design method based on the magnetic material distribution using genetic algorithm (GA). Proposed method can arrive at the practical solution with the multi-step utilization of GA, and the convergence speed is remarkably improved by using the combination of design space reduction against the conventional GA.

I. INTRODUCTION

The topology optimization based on the material distributions was firstly proposed by Bendsøe and Kikuchi [1]. The integer programming composed of huge ON-OFF design variables is conventionally converted to the continuous design space such as material density [2], [3], and the objective function can be minimized by deterministic approach using the design sensitivity. However, the type of minimized function is restricted to the differentiable one.

On the other hand, a heuristic method needs only objective function value. For example, immune algorithm with some special constraint conditions to prevent the generation of checkerboards or island element is successfully applied to the inductor optimization [4]. Furthermore, GA and ON-OFF sensitivity combinatorial method is proposed [5]. In this reference, initial chromosomes in first generation are generated by information of flux flow in magnetic circuits; it is difficult to identify the flux flow in such as rotating machine with the flux varying in all directions.

This paper presents the efficient global and local search method based on the multi-step utilization of GA. In proposed method, firstly, global solution is largely searched in most coarse mesh. Next, roughly result is assigned to fine mesh, and the number of design variables can be reduced by restriction of design space in the adjacent element with the contour of magnetic body. This paper validates the effectiveness of multi step GA with reduced design space against the conventional GA.

II. OPTIMIZATION METHOD

GA needs huge iteration of finite element analyses in the optimization problem composed of many design variables in the topology optimization based on ON-OFF material distributions. Then, we propose multi step GA. Firstly, the solution is largely searched in most rough finite element mesh as shown in Fig. 1. Next, previous optimal solution is assigned to the fine mesh. The assigned solution is set as first chromosome in first generation of GA. Therefore, the number of design variables in the fine mesh will be huge numbers. Then, design space is restricted to the adjacent element with outer contour of iron element in previous optimal solution. The number of design variables n_d can be reduced by half against the second design domain.

Flowchart of multi step GA with the reduction of design space is shown in Fig. 2. Firstly, step number N_s of GA is

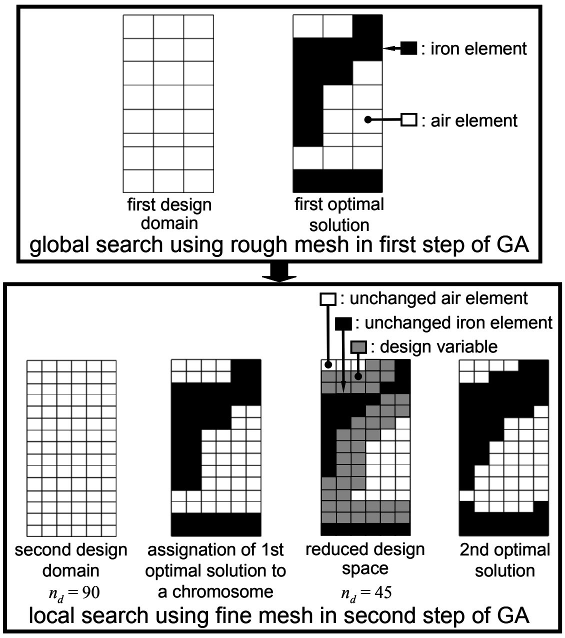

Fig. 1. Multi step GA and reduction process of design variables.

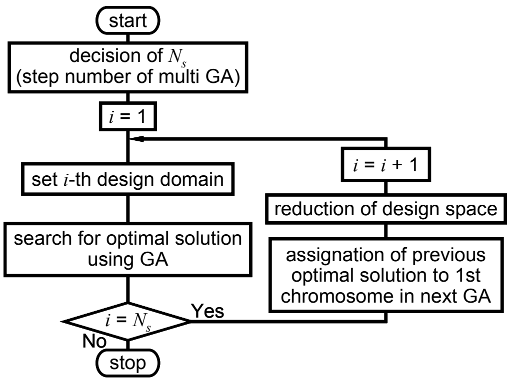

Fig. 2. Flowchart of multi step GA with reduction of design space.

decided, and GA is started in the design domain of i-th finite element mesh. Next, new design space is defined by assignation of previous solution to the next fine mesh. Furthermore, rough solution is defined as 1st chromosome in 1st generation of next GA. The materials of other chromosomes in reduced design space are randomly decided as air or iron. And, GA is restarted again in the fine mesh. These procedures will be iterated until carrying out N_s-th GA search.

III. OPTIMIZED MODEL

The 2-D magnetostatic model is shown in Fig. 3. The optimization object is maximizing the magnetic attractive force f_x on armature in x-direction on the condition that iron area S_{iron} in the design domain keeps less than area constraint S_0. The attractive force f_x is computed by nodal force method [6]. To achieve this design goal, the objective function W is formulated as follows:

$$W = 1 / f_x^{\,2} + P(S_{\mathrm{iron}}) \tag{2}$$

where $P(S_{\mathrm{iron}})$ shows the penalty function to take the constraint condition of iron area into account as follows:

$$P(S_{\mathrm{iron}}) = \begin{cases} k\,(S_{\mathrm{iron}} - S_0) & (S_{\mathrm{iron}} > S_0) \\ 0 & (S_{\mathrm{iron}} \le S_0) \end{cases} \tag{3}$$

where k shows the penalty factor which is set as 10^8.

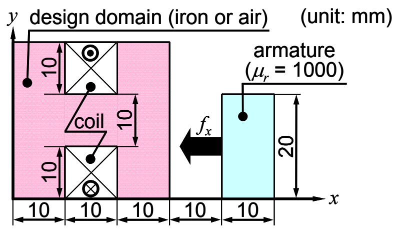

Fig. 3. Analyzed model.

IV. NUMERICAL RESULTS

The tuned parameter of multi step GA is shown in TABLE I. Four steps GA is adopted in this problem, so generation number in conventional GA is set as quadrupled value 600. Fitness is defined by the inverse of W. The roulette selection is performed by using the linear scaling of fitness to the power ten. Other parameter is same as multi step GA. The area constraint value S_0 is set as 4.0×10^{-4} m^2.

Fig. 4 shows the optimization results. The number of elements in design domain is simply doubled in order to increase the resolution of magnetic circuit. While conventional GA fails to realize the practical magnetic circuit, multi step GA has the success in derivation of useful solution because of considerable reduction of number of design variables as shown in TABEL II. If the operation of design space reduction is not considered in multi step GA, useful solution will not be realized.

TABLE I
TUNED PARAMETERS OF MULTI STEP GA

population number	generation number	crossover type	crossover ratio	selection	elite number
50	150	uniform	0.8	roulette	6

Fig. 5 shows the convergence processes of objective function. The characteristic of W in multi step GA converged faster than conventional GA. While the elapsed time in conventional GA is 1.4 hour, multi step GA needs only 0.47 hour in using PC with the specification of over-clocked CPU Intel Core i7 3.54 GHz and 12 GB RAM.

Multi step GA with the reduction of design space is successfully applied to the optimal design based on magnetic material distributions. The 3-D optimal design of more practical target will be performed in the full paper.

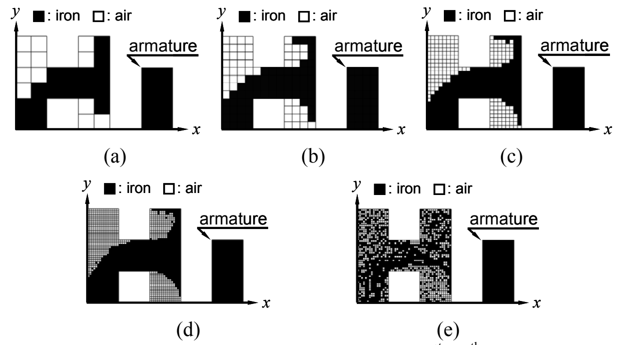

Fig. 4. Optimized material distributions : (a) - (d) 1st - 4th solution of multi step GA, respectively. (e) solution of conventional GA.

TABLE II
REDUCTION RATIO OF DESIGN VARIABLES IN MULTI STEP GA

step number of GA	1	2	3	4
initial number of design variables	28 (1.00)	112 (1.00)	448 (1.00)	1,792 (1.00)
reduced number of design variables	28 (1.00)	34 (0.27)	84 (0.19)	192 (0.11)

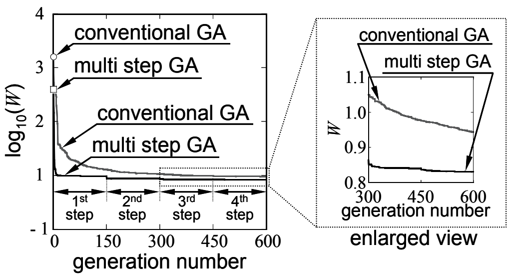

Fig. 5. Convergence process of objective function.

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