Search Region Management Method for Local Search Algorithm employing Design Optimization of Brushless DC Motor

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Optimal design of electric machine such as motor requires much computation time since it is performed through Finite Element Analysis for higher accuracy. For this reason, development of optimization algorithm is regarded as a requisite in order to reduce the number of objective function calls. In case of local search algorithm, it is not guaranteed whether global optimum solution can be searched effectively, or not. Therefore, in this study, we introduce the novel optimization method, Search Region Management (SRM), to improve characteristics of local search algorithm. SRM uses a Guided Random Bit Generation based on gray-code as region selection when local search iterates optimum search process for multi-start. In addition, it saves and manages the information of previous searched points to increase an effectiveness of local search during every iteration process. The proposed algorithm has been applied to brushless DC motor design optimization based on Finite Element Analysis.

***Index Terms*— Brushless Motors, Design Optimization, Electric Machines, Finite Element Analysis, Torque**

I. Introduction

DESIGN optimization of electric machines based on Finite Element Analysis (FEA) calls for considerable computation time in order to accomplish higher accuracy [1]. Therefore, when the objective function is evaluated by FEA, the optimization algorithm needs to be particularly efficient to reduce the number of objective function calls.

In searching optimal solution with a local search algorithm, it can give no guarantee that whether the solution is global minimum or local one. Among the various factors in global optimization, configuration of initial search points affects diversification aspect, which is beneficial for multimodal problems. Thus, initial point selection for multi-start strategy as well as local search algorithm should be considered as a requisite [2].

We introduce novel algorithm, Search Region Management (SRM), to improve initial point selection for multi-start by applying a Guided Random Bit Generation (GRBG) and handling with the past searched information of local search methods. In case of electric machine design, almost whole variables have constraint of range narrowly because of considering a basic design goal of size and manufacturing constraint [3]. This characteristic motivates the authors to develop SRM algorithm with local search method, especially considering design variables as region.

An effectiveness of the proposed optimization method has been validated through typical test functions. Finally, it is applied to a design optimization of Brushless DC (BLDC) motor whose cost functions are obtained by FEA.

II. Global and Local Search Algorithm

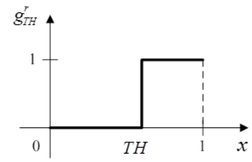
Optimization algorithms are classified in two categories. One is a stochastic optimal method which is global search algorithm and the other is a deterministic optimal method which is local search algorithm. Genetic Algorithm (GA), Particle Swarm Optimization (PSO) and etc. are included in global search algorithm. They can find a global optimum even in case of multimodal problem by searching widely, but need many repetitions to guarantee it. Local search algorithms such as MADS, simplex method, pattern search method, and etc., can search optimum solution with the fast convergent property. They can, however, converge to local optimum. Therefore, they need to be combined with global optimization method, multi-start in this study, to search a global minimum, efficiently [4], [5].

III. Search Region Management Method

In this research, SRM algorithm includes two concepts; one is GRBG based on gray-code for initial point selection, the other is information management of the past searched point as region for stop conditions.

A. Guided Random Bit Generation for Multi-start

For stochastic selection of an initial point whose region has not been visited so far, GRBG is newly proposed with gray-code. GRBG makes region select, and the initial points of local search algorithm are decided at the center of selected regions in every iteration. GRBG simply generates repulsive or attractive random codes with bitwise flipping function $g^{r}_{TH^k}(x)$ shown in Fig. 1, where TH represents threshold of the uniformly distributed random variable, $x \in [0,1]$.



$$g^r_{TH}(x) = \begin{cases} 0, 0 \le x < TH \\ 1, TH \le x \le 1 \end{cases}$$

Fig. 1. Repulsive bitwise flipping function of GRBG

Assume that the k-th bit position has been assigned 1 more often than 0, and local search needs a farther, i.e., repulsive, point at the r-th restart. Then, it is desirable to assign a frequency of bit 1 for the k-th bit position, $n^{(1)}_k$, to TH such that

$(TH^{(k)} = n_k^{(1)}/r)$. Therefore, in case of $(n_k{}^{(1)}/r > 0.5)$, it is more probable to generate 0 rather than 1 for the k-th bit. Note that the general random flipping function corresponds to $g^r_{TH^k}(x)$ with $TH^{(k)}$ fixed to 0.5.

B. Searched Points Management for Iteration Stop Conditions

After the initial point generation with region selection through GRBG, local search is applied for optimum solution from the attained initial points. SRM, proposed algorithm, improves features of local search algorithm through following;

(a) Information management of the past searched points.

(b) Stop Condition 1: If an initial point, selected by GRBG, belongs to the region that includes more than n_v points already visited by local search, SRM does not let local search start from it but regenerates an initial point again.

(c) Stop Condition 2: In the local search procedure, if the trial point is in the region containing more than n_e past searched points, it is regarded as highly crowded area and stops the local search iteration.

By virtue of SRM algorithm and the past searched points information, local search method can considerably reduce the iteration and computation point number. Fig.2 represents a flow chart of SRM algorithm employing local search method.

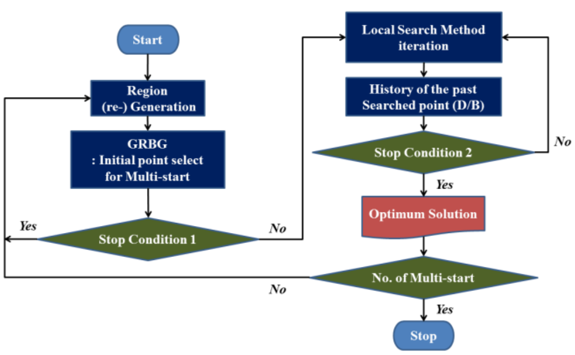
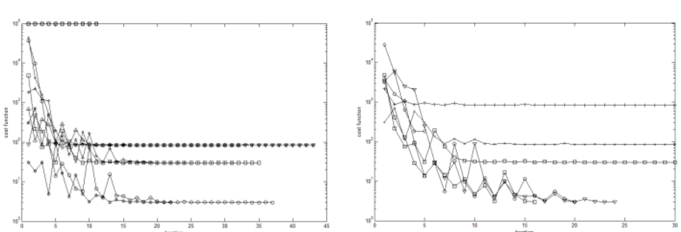


Fig. 2. Flow chart of SRM algorithm with local search method

C. Test Function Result

To confirm the performance of the proposed optimization, SRM algorithm employing local search method, MADS, Goldstein-Price function is employed as an example. As a result, SRM with MADS probed about 43% less points (670 points) than the conventional MADS (1,176 points). In other words, SRM with MADS can search more widely and evenly with less computation time than the conventional method by virtue of the past searched points data management and multi-start of GRBG using gray-code. Figs. 3 illustrate the profiles of the cost values while MADS has carried out 10 iterations.



(a) Cost function result of MADS with conventional multi-start

(b) Cost function result of MADS with SRM

Fig. 3. Result comparison of the proposed method to benchmark function

IV. Design Optimization of Brushless DC Motor

The design specification of BLDC motor for Engine Cooling Fan discussed in this study is summarized in Table I.

The design variables are assigned to magnet side chamfering (x_1, x_2), thickness (x_3), flattening (x_4), and notch (x_5) of stator teeth, as shown in Fig. 4. The design constraint is average torque more than 1.22 [Nm] and objective function is torque ripple minimization.

TABLE I
Design Specifications of BLDC motor

	Parameters	Spec.	Unit
Performance	Torque	1.22	[Nm]
	Speed	2500	[r/m]
General	No. of Pole and Slot	8 / 12	
	No. of Phase	3	
Rotor (Exterior-rotor)	Outer Diameter	115	[mm]
	PM Property	Ferrite-9BD	

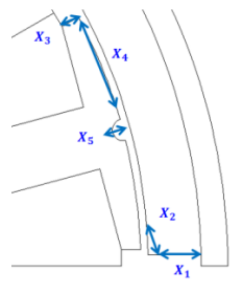


Fig. 4. Design variables for the optimal design of BLDC motor

V. Conclusion

In this study, we introduced the novel optimal algorithm, SRM, including GRBG based on gray-code and local search method for electric machine design. GRBG based on gray-code affected to multi-start improvement, and SRM reduced the number of evaluation points of local search by managing information of the past searched points. When applied to benchmark function, SRM with MADS, which is an example algorithm as local search one, probed global optimum about 43% less points than the conventional multi-start method with MADS. The design optimization of BLDC motor for Engine Cooling Fan was implemented by applying SRM with MADS through FEA.

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