Novel Topology Optimization Based on On-Off Method and Level Set Approach

Yuki Hidaka, Takahiro Sato and Hajime Igarashi
Graduate School of Information Science and Technology, Hokkaido University
Kita 14, Nishi 9, Kita-ku, Sapporo, 060-0814, Japan
hidaka@em-si.eng.hokudai.ac.jp

***Abstract*—This paper presents a new topology optimization method based on the on-off method and level set approach. In this method, local search is carried out using the level set approach subsequently to the global search with the on-off method. In order to test the present method, the rotor shape of an interior permanent magnetic motor (IPM-motor) is optimized. It is shown that the resultant motor properties are better than those obtained by the conventional on-off method.**

***Index Terms*—Design optimization, Permanent magnetic motors, Genetic algorithms, Level set.**

I. Introduction

Shape optimization plays an important role in the development of electromagnetic devices. There are two approaches to the shape optimization, namely, parameter and topology optimization methods. In the parameter optimization, device shapes are represented with geometric and material parameters and optimization is carried out by changing them [1]. On the other hand, the topology optimization seeks for the optimum solutions directly varying the material shapes without the geometric parameters [2].

In the topology optimization, the on-off method and the level set method have widely been used [2] [3]. In the on-off method, device shapes are expressed by binary pixel images and are optimized by changing the binary status of the pixels. In the on-off method, genetic algorithm (GA) is often employed for the optimization algorithm. Although the GA-based on-off method would have good performance for the global search, it tends to converge to complicate shapes and has poor local search ability. The level set method expresses material boundaries in terms of the level set functions. This method advantageously results in smooth boundaries and non-porous material region [3]. In optimization, level set function is updated to improve the value of object function. Since the level set method is based on gradient method, this method would have poor performance for the global search.

In this paper, we present a new topology optimization method which combines the on-off method with level set method. In the present method, first, the global search is performed based on the on-off optimization. Then, the solutions obtained by the on-off optimization are improved by the level set based optimization, which can effectively perform the local optima. It is expected that the final solution obtained by the present method has higher fitness in comparison with the solution obtained by the on-off method. Moreover the present method would filter out the spatial high-frequency components in the material boundary. In order to test the present method, in this work, the rotor shape of an IPM motor is optimized.

II. Optimization Method

A. Two-Stage Optimization

In the present method, global and local searches are performed by the GA-based on-off method and gradient-based level set method, respectively. In the first step, the global search is performed by the GA-based on-off method. The resultant solution would have relatively good fitness value although it has complicated material boundaries. In the second step, local search around the solution obtained in the first step is carried out using the level set method. It is expected that the fitness is further improved by the local search and the material boundaries are made smooth. Outline of the present method is shown in Fig. 1.

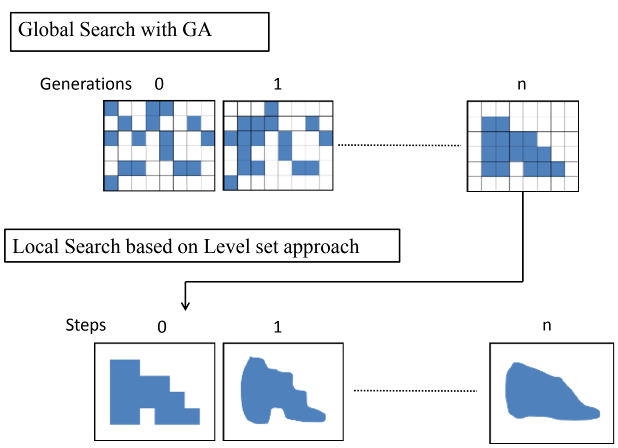


Fig. 1. Outline of the present method

B. Global search method

The micro genetic algorithm (μGA) is employed for optimization algorithm of the on-off method. Because μGA has few populations compared with conventional GA, we can suppress calculation time to evaluate fitness of the individual. If stagnation is observed in the optimization process, the individuals except elite solution are reinitialized randomly [4]. To avoid complicated material shapes with many islands and holes, filtering process is employed [5].

C. Local search method

As mentioned above, the local search is performed using the level set method. The level set function is defined as follows:

$$\phi(\boldsymbol{x})\begin{cases} >0 & \boldsymbol{x}\in\Omega \\ =0 & \boldsymbol{x}\in\partial\Omega \\ <0 & \boldsymbol{x}\in D\setminus\Omega \end{cases}, \quad (1)$$

where D, Ω and $\partial\Omega$ are design region, material region and material boundary respectively and $\boldsymbol{x}$ is a point in D. In level-set-based topology optimization, time evolution of $\phi(\boldsymbol{x})$ is governed by

$$\frac{\partial\phi(\boldsymbol{x},t)}{\partial t}+\frac{\mathrm{d}F}{\mathrm{d}\phi}=0\,. \quad (2)$$

where F denotes the objective function. Since it is difficult to evaluate $\mathrm{d}F/\mathrm{d}\phi$ analytically, it is computed using the adjoint variable method [5].

III. NUMERICAL RESULT

A. Optimization problem

In this work, to test the present method, we optimize the rotor shape of an IPM-motor shown in Fig. 2(a) [6]. Due to the symmetry in this model, 1/4 of the whole model is analyzed. The purpose of this optimization is to maximize the torque average and minimize the torque ripple of the IPM-motor. The objective function defined by

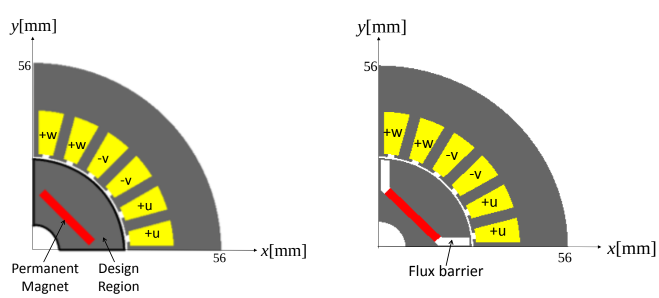
$$F(\phi)=-\frac{T_{average}}{T^0_{average}}+W\frac{T_{ripple}}{T^0_{ripple}}, \quad (4)$$

is minimized where W is a weighting coefficient, $T_{average}$ and T_{ripple} are torque average and torque ripple. In (4) the normalization constants are set as $T^0_{average}$ = 3.971 Nm and T^0_{ripple} = 0.353 which are obtained for the reference model shown in Fig. 2(b).

The flux barrier shape is first optimized by the on-off method. Subsequently to this step, the resultant shape is used as the initial solution for the level set method. In this method, the magnetic reluctivity, $\nu(\boldsymbol{x})$, is expressed by the level set functions as follows:

$$\nu(\boldsymbol{x})=\nu_0+H(\phi(\boldsymbol{x}))(\nu_m-\nu_0), \quad (5)$$

where $H(\phi)$ is the sigmoid function.



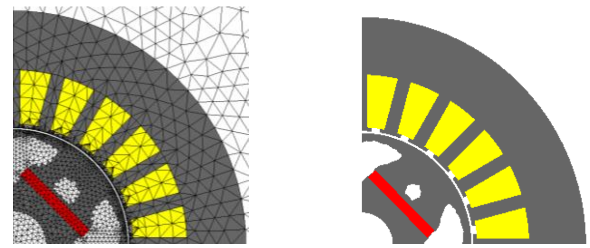
(a). Motor model (b). Reference model with flux barrier

Fig. 2 Optimization model

B. Numerical Result

The solutions obtained by the present method and the conventional on-off method are shown in Fig. 3. The values of torque average, torque ripple, and objective function are summarized in Table. I. Fig. 4 shows the torque evolutions in time. It is concluded from these results that both the average torque and ripple are improved by the local search performed with the level set method.

In the full paper, optimization process will be reported in detail and optimization results for other problems will be presented.



(a). Conventional on-off method (b). Present method

Fig. 3. Optimized shape

TABLE I
OPTIMIZATION RESULTS

	Conventional on-off method	Present method
$T_{average}$ (Nm)	4.592	4.839
T_{ripple}	0.180	0.0411
Objective function	-0.645	-1.102

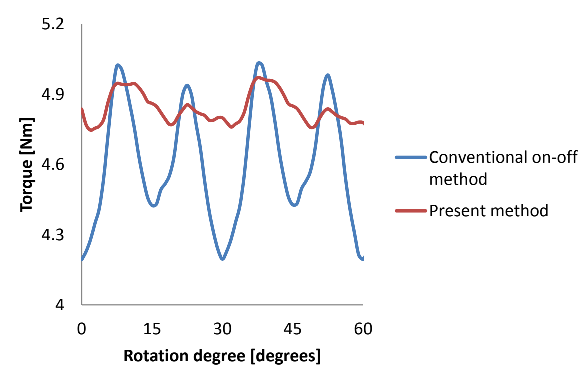


Fig. 4 Comparison of torque

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