Design of Rotor Structure in Brushless DC Motor with Concentrated Windings Using Genetic Algorithm Combined with Cluster of Materials

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Abstract — This paper proposes a novel topology optimization method for the material distribution of electrical machines using the Genetic algorithm combined with the cluster of materials and the cleaning procedure. The cluster of materials is taken into account not only to form the group of iron and the group of air but also to form the group of the *r*-oriented, the *x*-oriented and the *y*-oriented magnets. Consideration of the *r*-oriented magnet gives a surface permanent magnet type rotor, and consideration of the *x*-oriented and *y*-oriented magnets gives an interior permanent magnet type rotor.

I. Introduction

Several kinds of topology optimization have been proposed, because they are to be very promising. The topology optimization has a possibility to obtain an initial conceptual structure that designers could not imagine beforehand. About fifteen years ago, the topology optimization method was proposed [1], [2]. After these papers, several papers have been published. For example, Byun et al. proposed the topology optimization with design sensitivity [3]. Im et al. proposed the local optimization algorithm, called the ON/OFF sensitivity method, hybridized with GA to improve the convergence characteristics [4]. Wang et al. designed electromagnetic systems by the topology optimization considering magnetization direction [5]. Shim et al. proposed the topology optimization coupled with magneto-thermal systems [6]. Kim et al. designed a 3-D electromagnetic device with soft magnetic composites using the topology optimization method [7]. Choi et al. proposed an optimization method by Genetic algorithm an ON/OFF sensitivity considering the blurring technique to avoid the small structure spots [8]. Labbe et al. considered the mapping function to improve the convexity in the topology optimization [9]. Kikuchi et al. applied the topology optimization to the coupled magneto-structural problem [10]. Takahashi et al. designed IPM motor by ON/OFF method considering the magnetic nonlinearity and the rotation [11]. Park et al. optimized magnetic actuators using level-set method [12]. Watanabe et al. optimized an inductor using the Evolutionary algorithm [13].

The author also proposed a topology optimization method to optimize the material distribution of electrical machines using the GA [14], and then proposed the concept of the cluster of materials [15]. The consideration of the cluster of materials and the cleaning procedure removes small pieces of iron scattered in the air, and also removes small structural spots in the iron. However, reference [15] considered two kinds of material only, and therefore, the method is similar to the ON/OFF method. This paper improves the previous method in order to take into account more than two materials. In the proposed method, a cluster of materials is taken into account not only to form the group of iron and the group of air but also to form the group of the r-oriented, the x-oriented and the y-oriented magnets in the Genetic algorithm. Moreover, the GA is iterated with the newly increased length of genes. The proposed method is applied to optimize the topology of the rotor structure in a brushless DC motor with concentrated windings.

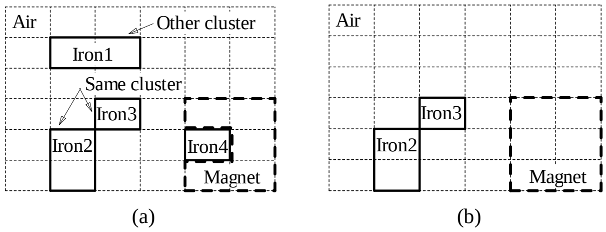

Fig. 1. The cluster of materials and cleaning method. (a) before cleaning, (b) after cleaning

II. Proposed Method

In the GA, the design region is discretized into a finite element mesh and the material of elements is set to a gene in the chromosome. This paper proposes the cluster of many kinds of material. For example, irons 2 and 3 form the same cluster, and iron 1 forms another cluster in Fig. 1(a). If the cluster is small, that is, the number of cells in the region is smaller than an integer N_{min}, the cleaning procedure is carried out. Then, irons 2 and 3 remain, and the other iron is dismissed. The iron 1 is changed to a surrounding material, air, and iron 4 is changed to magnet as shown in Fig. (b).

Moreover, this paper iterates the GA with the newly increased length of genes. At the first iteration, a rough topology is designed using a small number of design variables. And then, a fine topology is designed using a large number of design variables at the next iteration. Therefore, the computational cost can be reduced, compared with the method using a large number of design variables at the first iteration.

III. Optimized Results

A. Target brushless DC motor and fitness function

Fig. 2(a) shows the cross section of a brushless DC motor with concentrated windings. The whole rotor topology is to be designed. At the first iteration, one eighth of the rotor is divided into 5 by 9 cells, and 20 by 18 cells at

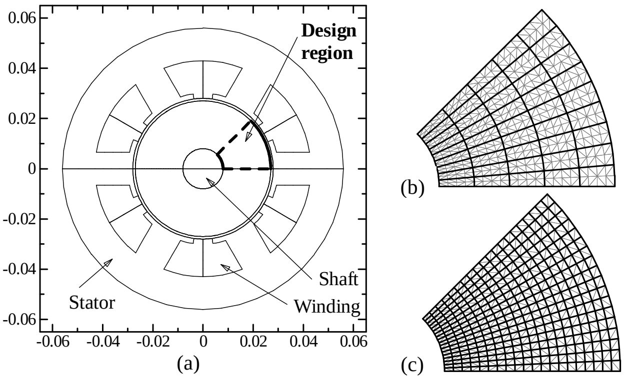

Fig. 2. The target brushless DC motor and the cells in the rotor. (a) motor cross section, (b) cell at the first iteration, (c) cell at the second iteration

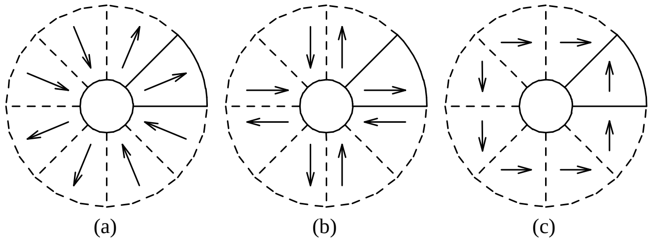

Fig. 3. Magnetized direction in permanent magnets. (a) *r*-direction, (b) *x*-direction, (c) *y*-direction

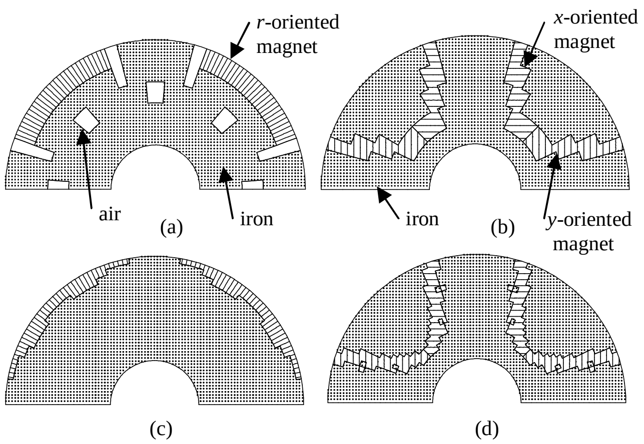

Fig. 4. Obtained rotor structures. (a) consideration of the *r*-oriented magnet, air and iron at 1st iteration, (b) the *x*- and *y*-oriented magnets, air and iron at 1st iteration, (c) the *r*-oriented magnet, air and iron at 2nd iteration, (d) the *x*- and *y*-oriented magnets, air and iron at 2nd iteration

the second iteration. This paper deals with three magnetized directions of permanent magnet as shown in Fig. 3. The torque is calculated using the 2D FEM by rotating the rotor, where it is assumed that the shape of stator current is a sinusoidal.

The fitness function is defined as

$$fitness = \frac{T_{ave}}{kV_{pm}/V_{rotor} + 1} \tag{1}$$

where, T_{ave}, V_{pm}, V_{rotor} and k are is the developed average torque, the volume of permanent magnet, the volume of rotor, and a constant, respectively.

B. Optimized results

Figs. 4 (a) and (b) show the obtained results at the first iteration, where N_{min}=1 and k=5. Consideration of the iron, air and the *r*-oriented magnet gives a kind of surface permanent magnet type rotor, and the consideration of the iron, air, and the *x*-oriented and *y*-oriented magnets gives a kind of interior permanent magnet type rotor. At the second iteration, more fine shapes of the rotor are obtained as shown in Figs. 4(c) and (d). In conclusion, the initial conceptual structures of the rotor have been obtained by using the proposed method.

IV. References

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