Optimization of Rotor Topology in PM Synchronous Motors by Genetic Algorithm Considering Cluster of Materials and Cleaning Procedure

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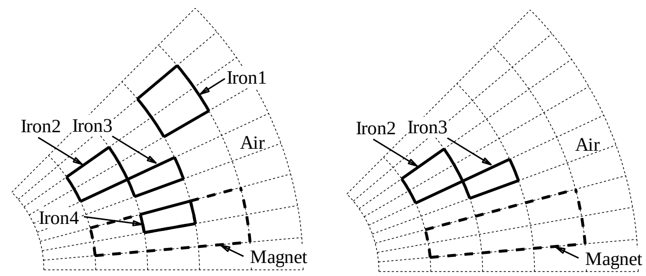
***Abstract*— This paper optimizes the topology of the rotor structure in interior permanent magnet type synchronous motors by the Genetic algorithm (GA) considering the concept of the cluster and the cleaning procedure of material. The difference between the concentrated and distributed stator windings, and between sinusoidal and rectangular current driving methods is investigated. Moreover, the effect of the kinds of magnet material and the fitness function is clarified.**

***Index Terms*— Topology optimization, genetic algorithm, permanent magnet synchronous motor, finite element method.**

I. INTRODUCTION

Topology optimization allows one to obtain an initial conceptual structure starting with minimal information on the object's structure. Therefore, several papers have been published concerning this optimization method. For example, a topology optimization with design sensitivity was proposed [1]. The ON/OFF sensitivity method hybridized with the genetic algorithm (GA) was proposed to improve the convergence characteristics [2]. Electromagnetic systems were designed by considering magnetization direction [3]. A topology optimization coupled with magneto-thermal systems was proposed [4]. A 3-D electromagnetic device with soft magnetic composites was designed [5]. In [6] an optimization method which uses the genetic algorithm and the ON/OFF sensitivity in conjunction with the blurring technique to avoid small structure spots was proposed. A mapping function was considered to improve convexity [7]. An internal permanent magnet (IPM) motor was designed using the ON/OFF method considering magnetic nonlinearity and rotation [8]. Magnetic actuators were optimized using a level-set method [9]. An inductor was optimized using the evolutionary algorithm [10].

Authors have proposed a topology optimization method considering the concept of the cluster and cleaning procedure of material [11]. And then, we have improved the previous method in order to take into account more than two kinds of material, namely, air, iron, *r*-oriented, *x*-oriented and *y*-oriented magnets [12]. This paper optimizes the topology of the rotor structure in PM synchronous motors. Two kinds of stator windings, that is, the concentrated and distributed ones, and two types of current driving methods, that is, sinusoidal and rectangular ones, are taken into account. Moreover, the effect of the kinds of magnet material and the fitness function on the optimized rotor topology is discussed.



(a) Before cleaning, (b) After cleaning when N_{min}=2

Fig. 1. An example of the cluster and cleaning procedure

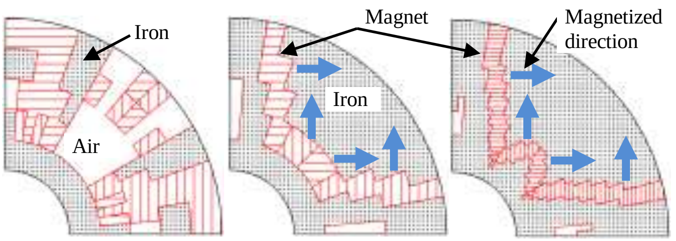
II. TOPOLOGY OPTIMIZATION METHOD

The GA is suitable for optimization problems containing a large search extent. The design region is discretized into FE meshes and the material of several elements, say, a cell, is set to a gene in the chromosome. We have proposed to introduce the concept of the cluster of many kinds of material into the GA. If the cluster is small, that is, the number of cells in the region is smaller than or equal to an integer N_{min}, the cleaning procedure is carried out. This cleaning procedure for the small cluster of material can remove the floating pieces of the material as shown in Fig. 1. In order to restrain the volume of the PM and to acquire the structure for large average torque, the fitness function is defined as

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

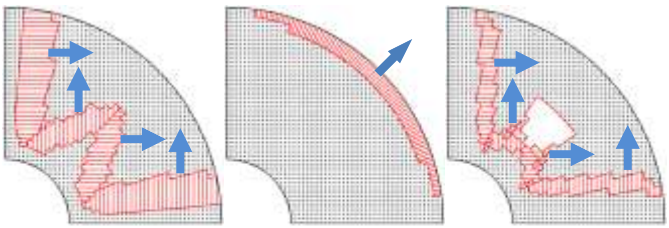
where, T_{ave}, V_{pm}, V_{rotor}, and k are the average torque, the volume of PM, the volume of rotor, and a constant, respectively. The magnetic field in the PM motor is calculated with two-dimensional FEM, and then the torque is calculated with the Maxwell's stress tensor method. The population and the number of generations in the GA are chosen to be 45 and 300, respectively.

This paper investigates two types of 4-pole stator winding, that is, a concentrated winding for 6 stator teeth and a distributed winding for 24 stator teeth. One eighth region of the rotor is to be designed because of symmetry. For the 1st iteration, one eighth of the rotor is divided into 5 by 9 cells, and 20 by 18 cells for the 2nd and 3rd iterations. This paper also investigates two types of stator current waveform, that is, a rectangular current and a sinusoidal current.

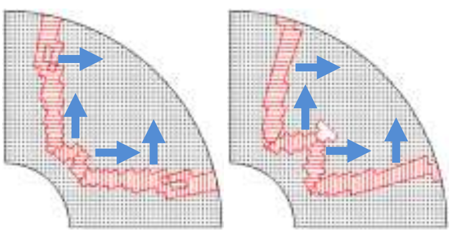


(a) At the first generation, (b) At 300-th generation, (c) Final

Fig. 2. Obtained rotor topologies for concentrated winding and sinusoidal current



(a) For k=1, (b) For r-oriented magnet, (c) For rectangular stator current,



(d) For distributed winding and sinusoidal current, (e) For distributed winding and rectangular current

Fig. 3. Obtained rotor topologies for different stator windings and current driving methods

III. Optimized Results

Fig. 2 shows the obtained rotor topologies at the first generation and at 300-th generation in the first iteration, and the final generation. In this case, the stator has the concentrated winding and the stator current is sinusoidal. Four kinds of material, namely, air, iron, x-oriented magnet, and y-oriented magnet are taken into account. N_{min} is set to 1 for air and iron at the 1st iteration. This means that if the number of cells equals to 1, the material of the cell is changed to the surrounding material. N_{min} is set to 4 at 2nd and 3rd iteration for all materials. The constant k is set to 5. It is found that a very rough shape of the rotor is obtained at 300-th generation, and then a fine shape of the rotor is finally obtained.

Fig. 3(a) shows the case where k =1 and the other conditions are the same as in Fig. 2. The volume of PM is larger than that in Fig. 2(c), because it does not affect the fitness function very much if k is small. Fig. 3(b) shows the case where the r-oriented magnet is considered instead of the x- and y-oriented magnets. It is found that a surface permanent magnet type rotor is obtained by considering the r-oriented magnet and the interior permanent magnet type rotor is obtained by considering the x- and y-oriented magnets. Fig. 3(c) shows the case where the stator current is rectangular. It is found that the interior permanent magnet type rotor is also obtained but there is a part of non-magnetic material at the center of magnets. Fig. 3(d) shows the case where the stator has the distributed winding and the stator current is sinusoidal, and Fig. 3(e) shows the case where the stator has the distributed winding and the stator current is rectangular. It is found that the interior permanent magnet type rotors are also obtained and the shapes are approximately the same as in Figs. 2(c) and 3(c).

IV. Conclusions

This paper has optimized the topology of the rotor structure in the PM synchronous motor by using the GA considering the concept of the cluster and the cleaning procedure of material. The magnet with large volume has been obtained by considering a small k. The surface permanent magnet type rotor has been obtained by considering the r-oriented magnet, and the interior permanent magnet type rotor has been obtained by considering the x- and y-oriented magnets. The rectangular current drive has given a hole in the center of magnets. The distributed winding has also given the almost same shape as the concentrated winding.

Since the obtained rotor shapes are slightly complex and less practical, the other conventional optimization technique is necessary to design the final shape.

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