A Novel Hybrid Algorithm Using Shape and Topology Optimization for the Design of Electric Machines

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The conventional topology optimization (TO) algorithm for an electric machine has a critical problem as the derivation of the impractical model to manufacture. In the case of a conventional step optimization, such as shape optimization (SO) after TO, the optimized model by TO is seriously distorted. To solve these problems of the conventional TO method for the electric machine, a novel hybrid optimization algorithm that can conduct SO and TO simultaneously is proposed in this paper.

Index Terms— **Design optimization, electric machines, finite element analysis, optimization methods, topology**

I. Introduction

SHAPE optimization (SO) and topology optimization (TO) have been extensively studied in electric machine designs until recently. In SO, geometric shapes are presented in terms of geometric parameters, and optimization is performed by varying them. On the other hand, TO looks for the optimum solutions directly changing the material properties without geometric parameters [1].

TO has received great attention from many researchers for several decades because it can suggest an innovative topology model. However, many methods using TO are restricted to the flux barrier design because the geometric shape and the position of the magnet are fixed in these algorithms [1]. Ishikawa has proposed a new TO method [2]. This method conducts TO for the whole area of the rotor. After the modification of the topologically optimized model taking into account the manufacturability, SO is conducted. Hence, the topologically optimized model is distorted seriously via the modification and SO process.

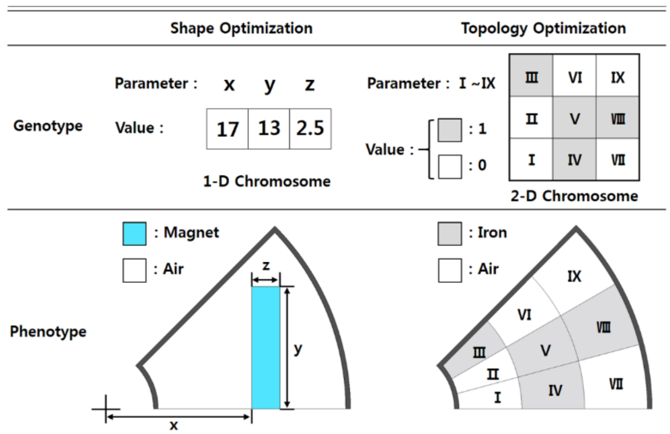
To address the above problems, a novel hybrid optimization algorithm is proposed in this paper. The proposed algorithm can conduct the SO of the magnet and the TO of the flux barrier simultaneously to derive a practical model and mitigate the distortion of the topologically optimized model. Hence, we termed the proposed method as a novel hybrid algorithm using shape and topology optimization (HASTO) in this research. The usefulness of the proposed HASTO method is verified via that application into the practical optimization as the cogging torque minimization for an interior permanent magnet synchronous machine (IPMSM).

II. The Proposed HASTO Method for the Design of Electric Machine

The genetic algorithm (GA) is one of the stochastic algorithms that use selection, crossover, and mutation operators. In this paper, to apply the HASTO method to the IPMSM design, we utilized GA that has the advantage of being able to represent the solutions as one-dimensional (1D) and two-dimensional (2D) chromosomes, and increasing the diversity of the solution by using geographic crossover.

The detailed optimization technique is as follows.

TABLE I
Genotype and Phenotype of the Solution



The HASTO method generally uses real numbers and binary encoding for SO and TO, respectively.

A. *Definition of design parameters*

In this step, the design parameters should be defined. A straight-shape permanent magnet of IPMSM is represented by a 1D- chromosome for SO. The magnetic flux barrier of IPMSM is defined by a 2D- chromosome for TO. Table I shows an example of a genotype, which means a solution that is a set of design parameters when designing the rotor of an IPMSM through the HASTO method, and a phenotype, which means characteristics observable in the design domain according to the solution.

B. *Generation of initial population*

In this stage, initial population should be generated randomly within boundary conditions. To conduct SO and TO simultaneously, one population consists of two chromosomes (a 1D- chromosome and a 2D- chromosome). Assuming that initial population has the same fitness values, selection, crossover, and mutation are performed.

C. *Selection, crossover, and mutation*

In the case of selection and mutation, it proceeds in the same way as the general GA. A typical crossover technique such as an arithmetic crossover is used for a 1D- chromosome, and a geographic crossover is applied for a 2D- chromosome [3]. Fig. 1 shows an example of the regional separation procedure for geographic crossover with three cuts. Initially, a region should be divided into several sub-regions using randomly generated cutting lines and assign the numbers to each gene as shown in Fig. 1(a). Finally, the entire region can be separable into two sections depending on whether it is even or odd as shown in Fig. 1(b) and (c).

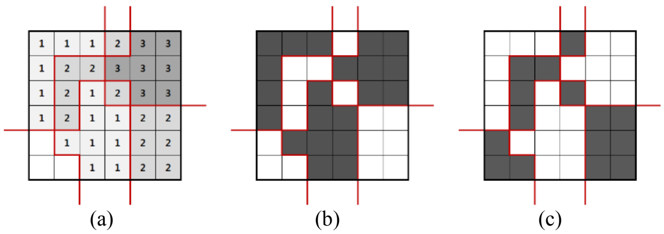


Fig. 1. (a) The numbers assigned to each gene by cutting lines. (b) and (c) The entire region divided into two sections by checking if the numbers in each gene are odd or even.

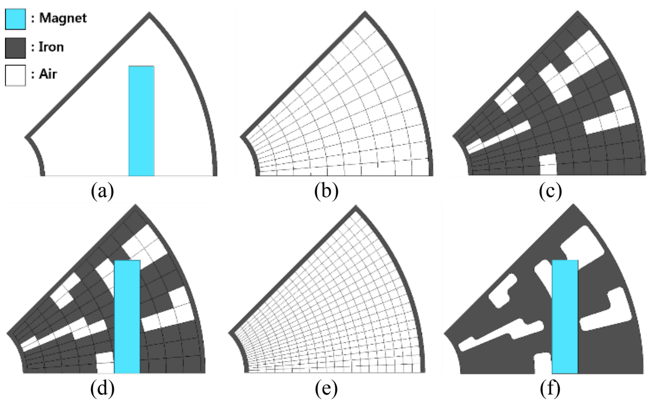


Fig. 2. (a) A magnet in the rotor generated by SO. (b) A design region divided into small cells for TO. (c) A flux barrier generated by TO. (d) A rotor structure combining (a) and (c). (e) A design region subdivided into fine cells from coarse cells for local optimization. (f) A final rotor structure through post-processing.

D. Pre-processing

Sometimes, offspring created through selection, crossover and mutation can be impractical. For example, small air spots and iron sub-regions surrounded by air can be created in the chromosome. Therefore, the pre-processing is required by replacing air with iron in the former case and by reversing in the latter case. In addition to that, the stress analysis has to be performed to confirm whether the designed result is reasonable in the mechanical aspect.

Solutions that satisfy practical and mechanical safety aspects are finally determined as the offspring. An example solution of the pre-processing is explained as shown in Fig. 2(a)-(d).

E. FEM analysis, fitness evaluation, replacement, and convergence check

The generated offspring model is analyzed using the finite-element method (FEM) analysis, and fitness is evaluated via objective functions. According to the fitness evaluation of the current generation, the population excluding the elite group is replaced by the better offspring. If the convergence condition is satisfied, post-processing is performed. Otherwise, the local optimization process is conducted.

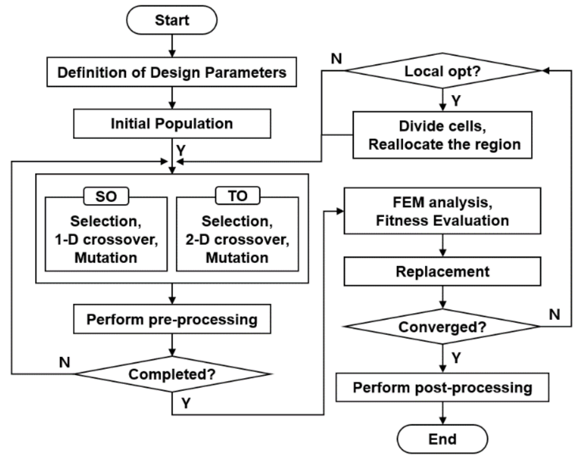


Fig. 3. The flowchart of the HASTO method

F. Local optimization and post-processing

In the initial generation, the optimization process is performed starting from a relatively large cell as shown in Fig. 2(b). When the local optimization condition is satisfied, each cell is subdivided as shown in Fig. 2(e). Then, the design area is reduced and reallocated based on the existing elite solutions. After that, the optimization process is resumed.

If the convergence is satisfied, fillet operations are performed individually on the elite group so that they can be a practical structure. Through the FEM analysis for them, one of them can be chosen as the final design. Fig. 2(f) shows an example of the post-processing result.

The entire flow chart of the proposed HASTO method is shown in Fig. 3.

III. Conclusion

The conventional TO algorithms for the electric machine have critical problems such as the derivation of the impractical model and the distortion of the optimized model. Hence, the remarkable achievement of this paper is that a manufacturable and practical optimized model can be derived by the proposed novel hybrid TO algorithm that combines SO and TO algorithms. It is also noteworthy in the aspect that an innovative and novel next-generation electric machines can be suggested via the application of the proposed algorithm into various kinds of electric machines.

References

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