Topology Optimization of Synchronous Reluctance Motor Using Component-Based Method

H. Cai. * and H. Zhao. †

* Southeast University, China
haiweicai@seu.edu.cn

Keywords: synchronous reluctance motor, component-based Method, vertex-based representation, topology optimization

Abstract

This study introduces a topology optimization method with an explicit and geometrical way that can represent the shape of air area with vertices. By applying genetic algorithm to optimize the position of vertices, better torque property can be obtained. It is shown that the proposed method has a better performance compared to conventional methods in two aspects: better torque property and practical structure.

1 Introduction

In recent years, synchronous reluctance machine (SynRM) is gaining the industry's attention due to its higher efficiency and low cost [1]. However, traditional parametric optimization cannot work well due to its complicate shape. To overcome the drawbacks of parametric optimization, researchers introduce topology optimization from mechanical.

Topology optimization can be divided into two categories: gradient-based method and gradient-free method. In the gradient-based method, such as solid isotropic material with penalization method (SIMP) [2], level set method [3].

In the gradient-free method, such as the ON/OFF method [4], it treats the design region as a binary image, assigning 0(air) and 1(material) to each pixel. Genetic algorithm then is applied to search the optimal distribution of materials. Recently, a component-based topology optimization has been proposed in mechanical [5]. it chooses geometry of component as basic variables. Compared to traditional pixel-based topology optimization, component-based method can do better in representation of objects and reduction of computational resources.

This paper introduces a topology optimization method for the design of synchronous reluctance machines which is based on components-based method. The proposed method defines the shape of air area in the rotor with polygons, while leaving the remaining part of the rotor as lamination material. By varying the location vertices of the polygons, the torque of the synchronous reluctance machine can be optimized.

2 Introduction to component-based method

To overcome the deficiency of traditional topology optimization, the component-based method uses components as the basic elements instead of pixel-based binary areas, and evolves the overall topology by changing the shape of each component. This method can incorporate more geometric information into the optimization process and reduce the number of parameters.

Level set function is used to describe the shape of components. However, there are two drawbacks for level set function. First, it is difficult to find suitable level function. Second, the rotor structure represented by level set function is often relatively simple.

3 Method of analysis

As described in part 2, in order to overcome deficiency of level set representation. We propose another simple and easy-to-implement method to represent the shape of components, that is using vertices to describe the shape of each component. It can leave out the process of choosing suitable level set function for each component. In this method, vertices are considered as control points to describe boundary between different materials. By connecting each vertex, the structure of a component is determined.

The procedures of the present method are summarized as follows.

1) Divide the design region into N sub region where the vertices of each component are located. Generate an initial population of N components with M vertices.

2) Sort these vertices to avoid strange shape.

3) Generate the corresponding rotor shape and calculate the torque using FEM.

4) Apply genetic algorithm to optimize coordinates of vertices.

5) Test a stop criterion. If it is satisfied, stop the procedures.

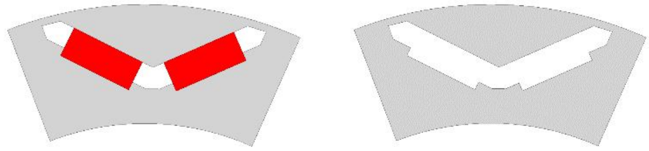
6) Back to step 2.

4 Optimization of SynRM

4.1 Optimization result

The 1/8 rotor of IPM model (Prius II motor) is shown in fig. 1a, by removing the PMs, as shown in fig. 1b, the IPM machine is reduced to a SynRM. The major parameters of reference model are listed in TABLE I.

We choose the whole rotor as design region. The design region is divided into 6 sub regions, due to symmetry, half of design region is considered to assign components. So there are 3 components are used in this case, and each component is composed of 6 vertices with 2 parameters, x and y coordinate, that is there are total 36 parameters to be optimized. The purpose of the optimization is to maximize the average torque and minimize torque ripple. Genetic algorithm is applied to optimize the multi-objective problem.



(a) rotor of IPM (b) rotor of SynRM

Fig. 1: Design region

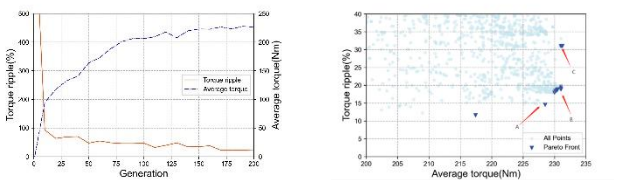
Parameter	Value	Unit
Stator outer/ inner diameter	269.2/161.9	mm
Rotor outer diameter	160.4	mm
Stack length	83.8	mm
Rated phase current RMS value	177	A
Rated speed	3000	r/min
Rated torque	144	Nm
Torque ripple at rated torque(%)	36.1	

Table 1: Main parameters of reference model

4.2 Problem setting

Fig. 2(a) shows the transition of the average of two objects for each generation. It can be seen from the figure that with generation increasing, average torque increases and torque ripple is reduced.

Fig. 2(b) shows the scatter plot during optimization, where pareto front is marked as triangle scatters. Some of the resultant structure of optimization is shown in fig. 3. It can be found that the resultant shape of rotor is fairly smooth and regular.



(a)Transition of two objectives (b)Pareto front

Fig. 2: Optimization result

(a) model A (b) model B (c) model C

Fig. 3: Structures of resultant model

5 Conclusion

In this article, we have proposed a topology optimization method which applies vertices to describe shape of component. It has been shown that the proposed method has more advantages in the following aspects compared to previous methods. First, by applying vertices to describe topology, the proposed method can have better performance than previous methods because vertices can describe geometry explicitly and arbitrarily. Second, the proposed method can obtain feasible and smooth structures compared to NGnet method because it applies structure components as basic element, which means no post-process needed compared to the traditional pixel-based method

References

[1] M. Murataliyev, M. Degano, M. Di Nardo, N. Bianchi, and C. Gerada, “Synchronous reluctance machines: A comprehensive review and technology comparison,” Proceedings of the IEEE, vol. 110, no. 3, pp. 382–399, 2022

[2] A. N. A. Hermann, N. Mijatovic, and M. L. Henriksen, “Topology optimisation of pmsm rotor for pump application,” in 2016 XXII International Conference on Electrical Machines (ICEM), 2016, pp. 2119– 2125.

[3] Y. S. Kim and I. H. Park, “Topology optimization of rotor in synchronous reluctance motor using level set method and shape design sensitivity,” IEEE Transactions on Applied Superconductivity, vol. 20, no. 3, pp. 1093–1096, 2010.

[4] S. Sato, T. Sato, and H. Igarashi, “Topology optimization of synchronous reluctance motor using normalized gaussian network,” IEEE Transactions on Magnetics, vol. 51, no. 3, pp. 1–4, 2015.

[5] X. Guo, W. Zhang, and W. Zhong, “Doing Topology Optimization Explicitly and Geometrically—A New Moving Morphable Components Based Framework,” Journal of Applied Mechanics, vol. 81, no. 8, 05 2014, 081009. [Online]. Available: https://doi.org/10.1115/1.4027609