Topoogy Optimization of Rotor in Synchronous Reluctance Motor Considering Torque Ripple by the GA with Cluster of Materials and Cleaning Procedure

Takeo Ishikawa\textsuperscript{1,2}, Senior Member, IEEE, Yuichiro Suzuki\textsuperscript{1}, and Yuya Ota\textsuperscript{1}

\textsuperscript{1}Division of Electronics and Informatics, Gunma University, Kiryu, Gunma 376-8515, Japan, ishi@gunma-u.ac.jp

The authors have proposed a topology optimization method to optimize the distribution of materials by the Genetic algorithm considering the cluster of material and a cleaning procedure. This paper optimizes the topology of rotor structure of synchronous reluctance motor for a high average torque and a low torque ripple by considering two materials. When the effect of torque ripple on the fitness function is chosen to be an appropriate value, several layers can be produced in the outside in the rotor to reduce the torque ripple.

Index Terms—Topology optimization, Genetic algorithm, synchronous reluctance motor, torque ripple.

I. INTRODUCTION

Synchronous reluctance motors (SynRMs) have some merits due to no permanent magnet. They are simple structure and low cost, and the efficiency reduction at a high temperature is lower than that of permanent magnet synchronous motors. However, the maximum torque and the efficiency of SynRMs are inferior to those of permanent magnet motors. The rotor with multiple flux barriers was introduced to realize a large torque, and the rotor shapes were optimized based on parameter optimization approaches \[1\], \[2\]. Since topology optimizations allow one to obtain an initial conceptual structure starting with minimal information regarding the structure of the object, they have been applied to the initial concept design of the rotor of SynRM \[3\]-\[5\].

The authors have proposed a topology optimization method to optimize the distribution of several materials in the rotor of permanent magnet synchronous machines using the Genetic algorithm (GA) considering the cluster of material and a cleaning procedure \[6\], \[7\]. In the proposed method, a high average torque was chosen to the objective function. This paper optimizes the topology of rotor structure of SynRM for a high average torque and a low torque ripple. The obtained rotor topologies are discussed using the torque waveforms.

II. PROPOSED TOPOLOGY OPTIMIZATION METHOD

Fig. 1 shows the cross section of a four-pole synchronous motor with distributed stator windings. One-eighth of the rotor is supposed to be designed. The proposed topology optimization method is composed of the GA coupled with the concept of cluster of material and a cleaning procedure. The GA is an algorithm that imitates the evolution of living things and is suitable for problems with a large sample space. The design region is split into two-dimensional finite element meshes, and the material of several elements, say a cell, is associated with a gene in the chromosome. We call the group of cells, which are connected to each other, as a cluster. If the number of cells in the cluster is smaller than or equal to an integer \(N_{\min}\), the cleaning procedure is executed. In the case of Fig. 2(a) and \(N_{\min} = 2\), Iron 1 and 2 are changed to the surrounding material air.

Iron 4 and 5 remain because they become one cluster. Iron 3 also remains because the number of cells is doubled and becomes four due to the periodic boundary. As a result, the material distribution becomes as shown in Fig. 2(b). Therefore, this cleaning procedure has the ability of removing the floating small pieces of iron.

III. OBTAINED ROTOR TOPOLOGIES AND DISCUSSION

In this paper, the following fitness function is used,

\[
\text{fitness} = \frac{T_{ave} - k_0 T_{ripple}}{k_1 S_{iron} / S_{rotor} + 1}
\]

where \(T_{ave}, T_{ripple}, S_{iron}, S_{rotor}, k_0\) and \(k_1\) are the average torque, the torque ripple, the areas of iron and rotor, and integers,
respectively. The integer \( k_1 \) is set to be 5 and \( k_0 \) is changed to investigate the effect of torque ripple. In the topology optimization, the number of individuals and generations are set to 45 and 300, respectively, and the crossover ratio is 0.2 and the mutation ratio is 0.02. \( N_{min} \) is set to 1 at the first iteration and 8 at the second iteration. The CPU time was 80 to 110 hours on Inter Core i7-4600U CPU, 2.1GHz, and it depends on the number of iterations for solving magnetic nonlinearity.

Fig. 3 shows the obtained rotor structures for the different \( k_0 \). Figs. (a) and (b) look similar, and Fig. (c) has a surrounding iron in the outside in the rotor. Fig. 4 shows the torque waveforms when the phase angle of stator current is set to be 45 degrees. When \( k_0 = 1 \), the torque ripple is much smaller than that for \( k_0 = 0 \). When \( k_0 = 5 \), the torque ripple becomes very small, but the average torque also becomes very small.

In order to investigate the reduction of torque ripple, Fig. 5 shows the flux distribution. In Fig. 5(b) the flux pass is separated to three as shown by a solid circle, on the contrary it is separated to two in Fig. 5(a). This parallel flux pass corresponds to the layers in the outside in the rotor. Therefore, when \( k_0 \) is chosen to be an appropriate vale, several layers can be produced in the outside in the rotor to reduce the torque ripple.

REFERENCES