A Study on the Optimizing design method of SynRM Rib thickness for High Torque and Efficiency

Jae-Kwang Lee[1] and Ki-Doek Lee[2]

[1]Department of Electrical Engineering, Hanyang University, Republic of Korea, jaekwanglee@hanyang.ac.kr
[2]Intelligent Mechatronics Research Center, Korea Electronics Tehnology Institute, Republic of Korea, kdlee@keti.re.kr

In this paper, we have studied the optimization of the rib thickness in design of Synchronous Reluctance Motor (SynRM). In the case of SynRM, mechanical stress is concentrated on the rib structure supporting the segment at high speed rotation, and the structural analysis results in the largest mechanical stress on the rib of d-axis. On the other hand, it was confirmed that relatively low mechanical stresses were distributed in the case of the q-axis rib. Therefore, it is confirmed that designing the thickness of the whole rib to be equally to the thickness that can support the maximum stress. And we can find that increases the magnetic flux leakage and is an inappropriate design method for reducing the output power. In order to prevent this phenomenon, the mechanical stress concentrated on each of the ribs was investigated, and a design method was developed to design the ribs with the optimized rib thickness. In addition, the thickness of the ribs that satisfying both the electromagnetic output and the mechanical safety factor was derived using the reaction surface method. Finally, we confirmed the improvement of the output using FEM analysis. And we verified the validity of the design method through actual testing.

***Index Terms*—SynRM, Rib Thickness, Synchonous Relectance Motor, High Efficiency, High Performance, Induction Motor**

I. INTRODUCTION

Recently, electric power consumption has been greatly increased due to the development of the electric equipment industry and the convenience of use of electricity. In order to cover the large-scale electric power consumption, the expansion of the power generation facilities and the improvement of the efficiency of the electric equipment are suggested as representative methods. As part of its efforts, MPES, which regulates the efficiency of industrial induction motors, which accounts for more than 50% of the power consumption, is being implemented mainly in developed countries. MPES is a system to regulate the efficiency according to the capacity of the induction motor. Research on improving the efficiency of the induction machine has reached saturation, so research on the development of high efficiency SynRM is actively being carried out. In this paper, we design the Synchronous Relectance Motor that satisfying the super premium class (IE4) and analyze the design variables that have a major influence on the output characteristics of the SynRM. The rotor structure of the SynRM is a structure in which a plurality of segments are combined with a rib structure and has a shape as shown in Fig.1. If the ribs are thick, mechanical strength becomes strong, and it may be advantageous for high-speed rotation. But magnetic flux leakage occurs through the ribs, which causes disadvantages in the electromagnetic output power. When the thickness of the rib is thin, magnetic flux leakage is reduced and the electromagnetic output power is increased. But the mechanical strength is weakened and there is a risk of scattering at high speed rotation. In general, the thickness of each rib is designed to be the same for ease of fabrication. However, as a result of the analysis, it was confirmed that the largest mechanical stress is generated in the inner rib close to the d-axis than the outer rib close to the q-axis. So optimizing design method for rib thickness should be considered.

II. LEAKAGE OF MAGNETIC FLUX THROUGH RIB

Fig. 1 shows the rotor structure of a typical SynRM that consist of the barriers, segments, ribs, and D-axis Q-axis respectively.

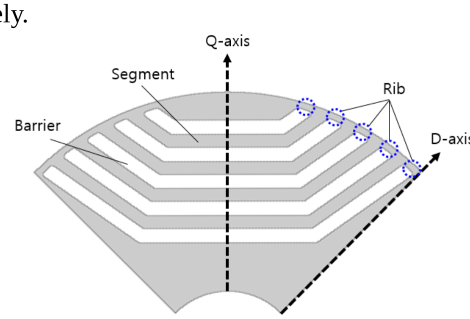


Fig. 1. Rotor structure of Synchronous Releuctance Motor

Fig. 2 shows the leakage of the magnetic flux generated in the rib structure of the SynRM motor through the magnetic flux line.

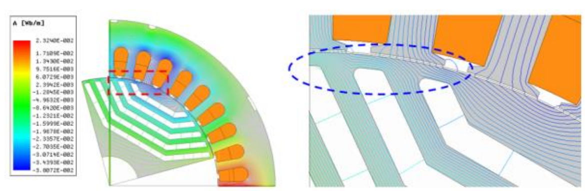


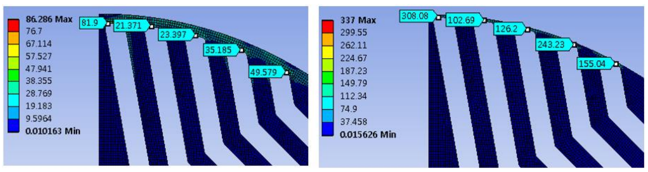
Fig. 2. Flux leakage in rib structure

Table 1 shows the electromagnetic characteristics and mechanical safty factor of a typical SynRM with the same rib thickness. And we are reducing the rib thickness.

TABLE I
OUTPUT CHARACTERISTIC ABOUT RIB THICKNESS

Rib Thickness [mm]	Torque [Nm]	Efficiency [%]	Safty Factor (2500rpm)
2	76.61	94.64	3.07
1.5	78.61	94.73	2.46
1	80.04	94.79	1.68
0.5	81.06	94.76	0.79

Table I shows that as the rib thickness decreases, the output power and efficiency of the electromagnetic performance are improved. It is also possible to confirm that the mechanical stiffness is reduced. In order to secure the driving stability in the high-speed operation section, the mechanical safety factor is designed for 2 or more. So 1mm and 0.5mm model is inappropriate about safty factor. Fig. 3 shows the results of analysis of the mechanical stiffness of a SynRM with the same rib thickness at 2 mm and 0.5 mm rib thickness.



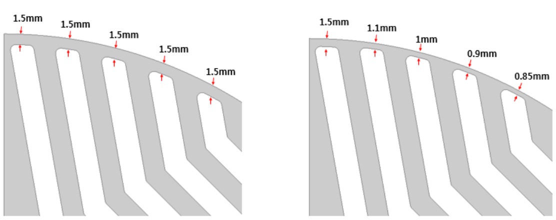
(a) (b)

Fig. 3. Stress distribution according to rid thickness in 2500rpm

Fig. 3 shows that the largest mechanical stiffness occurs in the ribs close to the D axis, and that the stress decreases in the Q axis. It can be seen from the analysis results that the thickness of the ribs is unified to the thickness of the ribs to support maximum stress. That is a design method for ensuring more than necessary mechanical rigidity and increasing flux leakage.

III. Optimizing method of Rib Thickness

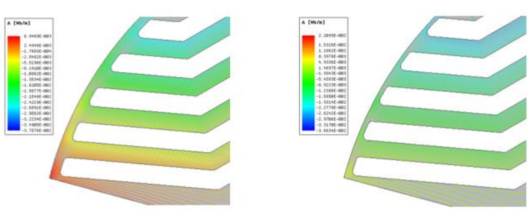
In the previous chapters, we concluded that the rib thickness from the D-axis to the Q-axis should reflect the optimal design for the mechanical stresses concentrated on each. The reaction surface method, which is an optimization technique, was used to derive the optimal rib thickness.



(a) (b)

Fig. 4. Optimized Rib Thickness of SynRM

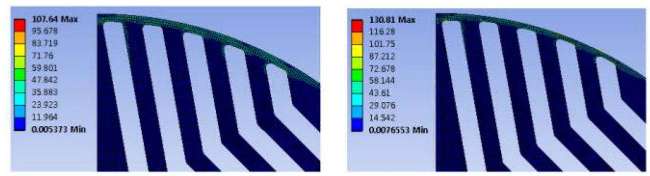
Fig 4-(a) shows a Rib thickness of typical SynRM and Fig 4-(b) is Optimizing Model that adapted independent rib thickness. As can be seen from the Fig. 4, it can be seen that the rib thickness becomes gradually thinner due to the decreasing mechanical stress toward the Q-axis from the D-axis.



(a) (b)

Fig. 5. Decreasing of Flux Leakage by Rib thickness optimization

Fig 5 shows flux leakage in both case tha rib thickness is 1.5mm and opmized rib thickness. It can be seen that the flux leakage decreases remarkably when the optimization is adapted Figure 6 shows the analysis results when the total rib thickness is 1.5mm and the analysis results when optimized. It can be confirmed that the maximum value of the stress is the similar when the overall rib thickness is designed to be same and when the rib thickness is made thinner.



(a) (b)

Fig. 6. Comparison of stress distribution typical model and optimized model.

Table II compares the electrical and mechanical output characteristics at typical model (1.5mm) and optimized model

TABLE II
Output characteristic Typical model and optimized model

Rib Thickness [mm]	Torque [Nm]	Efficiency [%]	Safty Factor (2500rpm)
1.5	78.61	94.73	2.46
Optimizing (1.5, 1.1, 1, 0.9, 0.85)	80.15	94.79	2.03

IV. Result

In this paper, we analyze the mechanical stress distribution and the electromagnetic performance change according to rib thickness using electromagnetic analysis and structural analysis. As a result, it has been confirmed that the mechanical stress concentrated on rib of D-axis. In that reasion the design method that the rib thickness should be designed by using optimizing method. In the full paper, we will add a process of the reaction surface method to help understand about design method. In addition, the motor designed with the same rib thickness and the motor with the optimized rib thickness are actually fabricated and tested to verify the reliability of the proposed design method.

V. Acknowledge

This work was supported by the Korea Institute of Energy Technology Evaluation and Planning(KETEP) and the Ministry of Trade, Industry & Energy(MOTIE) of the Republic of Korea (No. 20162010104100).

References

[1] Ki-Chan Kim, Joon Seon Ahn, Sung Hong Won, Jung-Pyo Hong and Ju Lee, “A Study on the Optimal Design of SynRm for the High Torque and Power,” *IEEE Tras.Mag*, vol. 43, no. 6, pp. 2543-2545, June. 2007.

[2] Won-Ho Kim, Kwang-Soo Kim, Seung-Joo Kim, Dong-Woo Kang, Sung-Chul Go, Yon-Do Chun and J.Lee, “Optimal PM Design of PMA-SynRM for Wide Constant-Power Operation and Torque Ripple Reduction,” *IEEE Tras.Mag*, vol. 45, no. 10, pp. 4660-4663, Oct. 2009.