Tooth Shape Design of Permanent Magnet Motor for Cogging Torque Reduction

Jae-Hoon Shim*, Min-Soo Choi, Kyu-Jin Jung and Jin-Kyu Byun
Department of Electrical Engineering, Soongsil University

1. Introduction

Recent advancements in high remanence permanent magnets and switching circuits have enabled proliferation of permanent magnet motors with high speed and accurate control. Cogging torque of a permanent magnet motor is caused by change of reluctance and magnetic energy with respect to relative position between stator and rotor, and is known to generate noise and vibration.

Cogging torque can be reduced by skewing rotor or stator, or changing the shape of the motor. In this paper, shape of the stator tooth is designed to reduce the cogging torque of a permanent magnet motor while maintain the average torque. The shape of the slot in the stator tooth has higher degrees of freedom compared to that used in the previous papers [1]-[2].

2. Model of the Permanent Magnet Motor

Fig. 1 shows the model of the 4-pole, 6-slot permanent magnet motor with stator diameter of 47 [mm], rotor diameter of 27 [mm], and air gap width of 0.4 [mm]. Permanent magnets have remanence of 0.65 [T] along radial direction. The objective function OF is set as follows in order to reduce cogging torque while maintaining the average torque:

$$\text{minimize: } OF = c_1 \left| T_{\text{cog } p-p} \right|^2 + c_2 \left| \frac{1}{T_{\text{avg}}} \right|^2 \qquad (1)$$

where $T_{\text{cog } p\text{-}p}$ is the peak-to-peak value of the cogging torque, T_{avg} is the average torque, and c_1 and c_2 are weighting factors for balancing cogging torque and average torque objective terms. The design variables are angle of the slot opening A and location of three points that determine the tooth shape (Fig. 2). COMSOL Multiphysics software was used for finite element analysis and torque calculation, and LiveLink with Matlab module of COMSOL was used for optimal design.

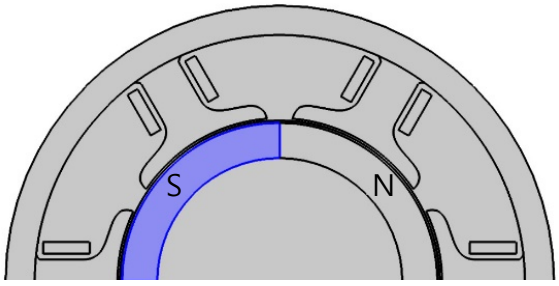


Fig. 1. Model of permanent magnet motor.

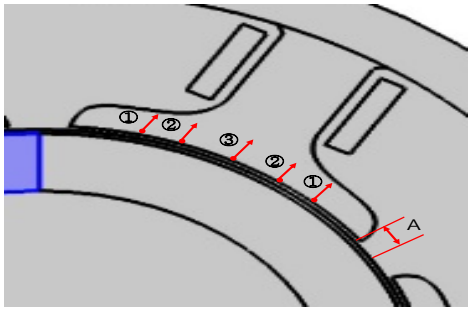
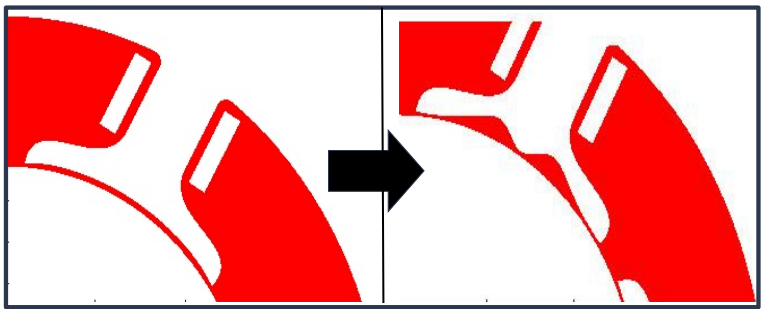


Fig. 2. Shape design variables for stator.

3. Design Results

Fig. 3 shows initial and final shape of the stator after optimization, while the values of design variables and torques are given in Table 1. The smooth arc-type slot was created in the tooth after the optimization. Cogging torque was reduced 78.9%, while average torque was reduced by 5.5%.



(a) Initial stator shape. (b) Optimized stator shape.

Fig. 3. Comparison of the stator shape.

Table 1. Design variables and torque before and after optimization.

	point① [mm]	point② [mm]	point③ [mm]	A [°]	T_{cog} [Nm]	T_{avg} [Nm]
Initial	0	0	0	4.5	2.567	18.562
Optimized	0.429	0.784	0.001	4.075	0.541	17.537

4. References

[1] Il-Hwan Park et al., "A Study on Reducing Cogging Torque by Core Shapes in Permanent Magnet Motors," *J. Korean Magn. Soc.*, vol. 20, no. 2, pp. 61-67, 2010.

[2] Jae-Hoon Kwon et al., "Optimal design of power tools BLDC motor for reducing cogging torque," *Proceedings of KIEE B Sector Fall Conference*, pp. 171-173, 2013.