Optimaization Design of Stator Notch Shape of Brushless DC Motor by Response of Surface Method

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Abstract— When low vibration, low noise and light weight of systems such as home appliances and automobiles are important, they are being replaced by BLDC motors. For motors that are often used in close proximity to people (such as home appliances and automobiles), vibration and noise reduction are important. To improve this, it is necessary to minimize the cogging torque, which causes vibration and noise of the motor.There is skew, slot open, and notch for reducing cogging torque. Notch method is advantageous in consideration of production cost and productivity. This paper infers the analytical expression of the cogging torque and proves that the notch shape is effective for reducing the cogging torque by using the self-equivalent circuit. Using notch shape as diameter, number of notch, and position, three parameters are selected. The nonlinear optimization technique, RSM (response of surface method), minimizes data analysis and computation time and derives optimal points of three variables. The RSM optimized design compares the simulation values of the cogging torque and the test measurements through two-dimensional finite element analysis and prototype fabrication. The comparative data verify the optimized design of the stator notch geometry of the SPM(Surface Permanent Magnet) BLDC motor

1. Introduction

- Cogging torque is a cause of vibration and noise in motors and should be avoided in home appliances and automobiles used by humans..
- In this paper, the optimization design of stator shape to reduce cogging torque of motor is studied.
- In order to reduce data analysis amount and analysis time, an optimal design was performed using response surface analysis.
- The results of the study are verified by finite element analysis and experimental experiments.

2. Basic model and magnetic equivalent circuit

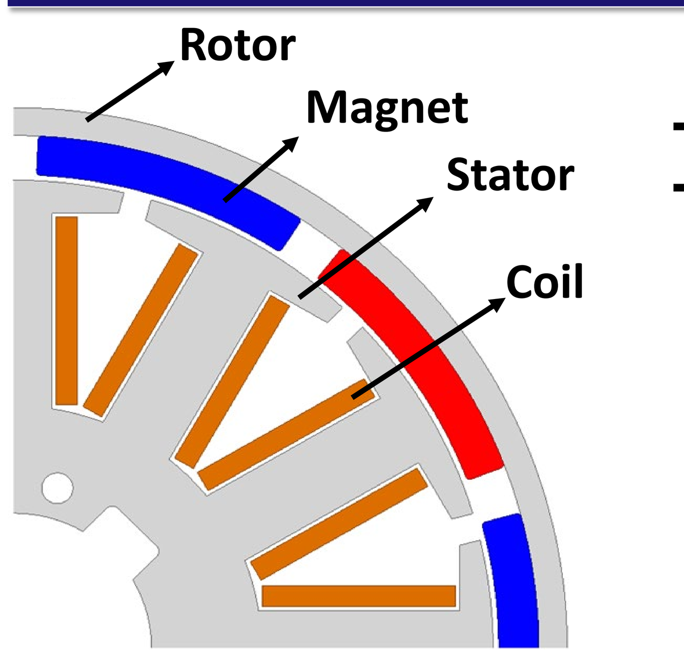

Fig. 1. SPM BLDC Basic Model.

TABLE 1
SPECIFICATIONS OF DISTRIBUTED MODEL

Structure	Parameter	Value	Unit
STATOR	Outer Diameter	119.5	mm
	Inner Diameter	61.8	mm
	Length	18	mm
	Number of Slot	12	-
ROTOR	Outer Diameter	138	mm
	Inner Diameter	130.9	mm
	Length	18	mm
	Number of Pole	10	-

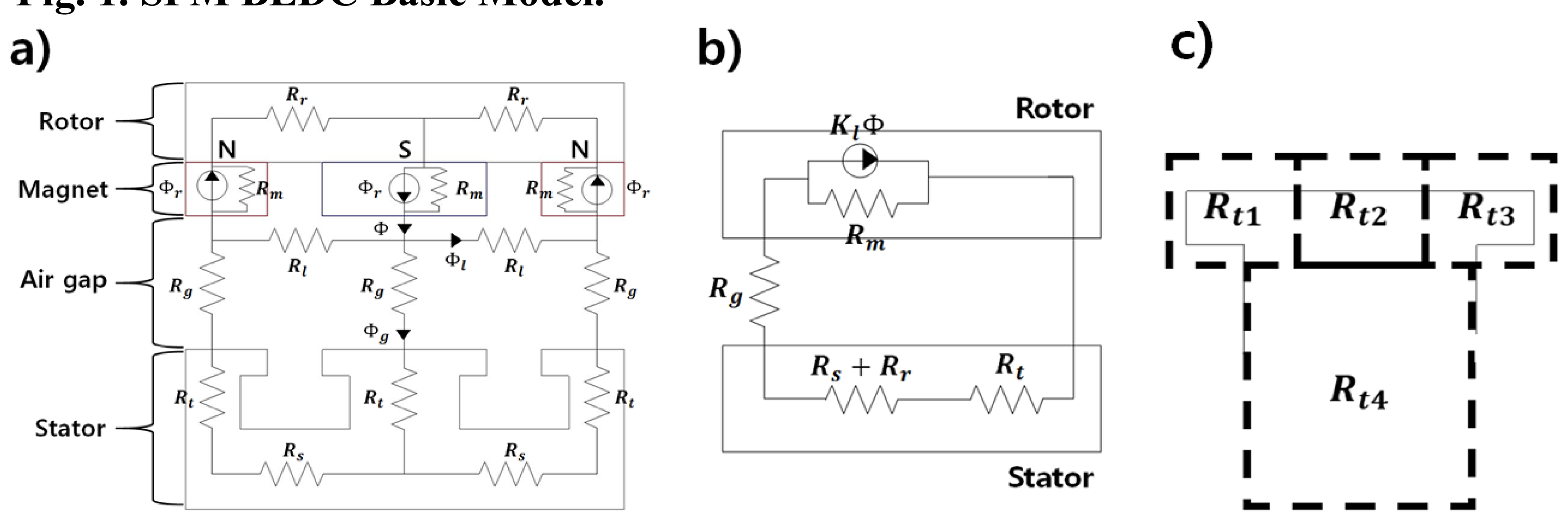

Fig. 2a) Magnetic circuit of SPM BLDC motor b) Simplified magnetic equivalent circuit c) Segmentation of magnetoresistance of stator tooth.

$$T_{cog} = -\frac{\Delta w_\alpha}{\alpha} \quad (1)$$

$$w \cong w_g = \frac{1}{2\mu_o}\int_v B_g^2\, dv = \frac{1}{2\mu_o}\int_v \frac{\Phi_g}{A_g}\, dv \quad (2)$$

$$w_g = \frac{1}{2\mu_o}\int_v \frac{K_l}{A_g}\frac{R_m\Phi_r}{R_g + R_s + R_r + R_t}\, dv \quad (3)$$

$$R_t = \frac{1}{\frac{1}{R_{t1}} + \frac{1}{R_{t2}} + \frac{1}{R_{t3}}} + R_{t4} \quad (4)$$

- It is a specification of the basic model to add the notch, and the magnetic circuit is designed according to the magnetic path.
- Equations (1) to (4) are derived through the self-equivalent circuit of Fig. 2 b).
- The stator notch reduces the air gap magnetic resistance, which reduces cogging torque.
- The magnetic flux is concentrated and saturation is caused by the difference in the magnetic resistance.

3. Optimization Design Using Response Surface Methodology

- When applying the notch to the motor, an optimum design suitable for the desired characteristic is required.
- For optimal design of notch, variables such as radius (r), angle (a), and notch of number (n) that affect the magnitude and magnetic path of magnetic reluctance are set.

TABLE 2
PARAMETER RANGE OF STATOR NOTCH

Parameter	Value	Unit
α_1	- 4 ~ 4	deg
α_2	- 11 ~ 11	deg
α_3	- 11 ~ 11	deg
r_1	0.5 ~ 4	mm
r_2	0.5 ~ 3	mm
r_3	0.5 ~ 3	mm

- Using Fig. 6, 7, 8, the optimum point can be estimated by considering cogging torque, output, torque, and counter electromotive force, respectively
- The point that is the intersection of each characteristic graph can be estimated as the optimum point.

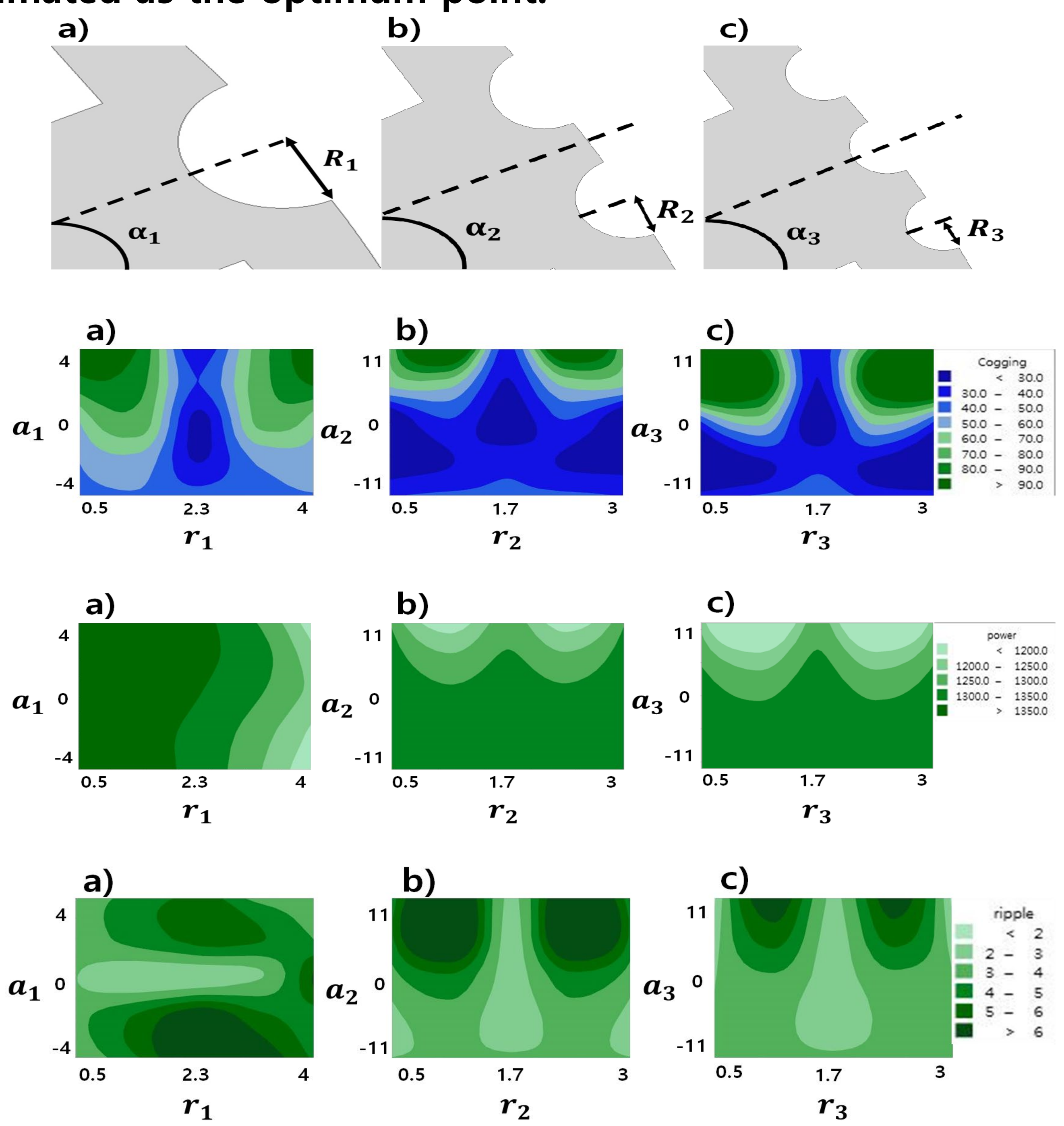

Fig. 3. Output characteristics versus cogging torque, output power, torque ripple a) 1 notch b) 2 notches c) 3 notches

4. Output characteristic comparison

- As the notch affected the magnetic concentration on Rt1 and Rt3, leakage increased, adversely affecting back EMF and efficiency, resulting in a slight decrease in efficiency and an increase in back EMF.
- Notch shape reduced output and efficiency, but the reduction of cogging torque is 12%, and the notch shape is effective.

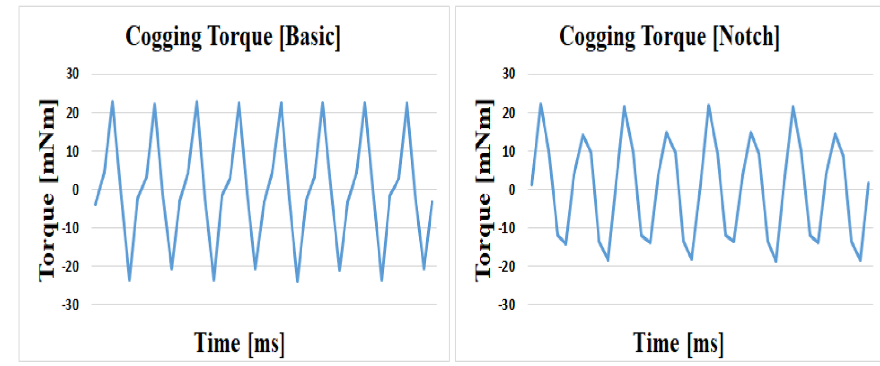

Fig. 4. Cogging Torque Simulation Data Comparison.

TABLE 3
Comparison of Output Characteristics of Base Model and Notch Model by Finite Element Analysis

	Basic Model	Notch Model	Unit
Torque	4.49	4.37	Nm
Output power	1269	1237	KW
Efficiency	86	85.8	%
Cogging Torque	46.66	40.89	mNm
EMF	14.58	14.67	Vrms
Magnetic Flux Density (Air gap)	329.7	309	mT

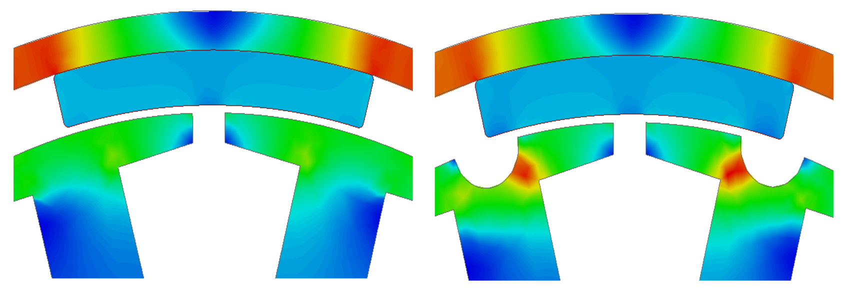

Fig. 5. Magnetic flux distribution according to shape

5. Prototyping and Experimental Measurement

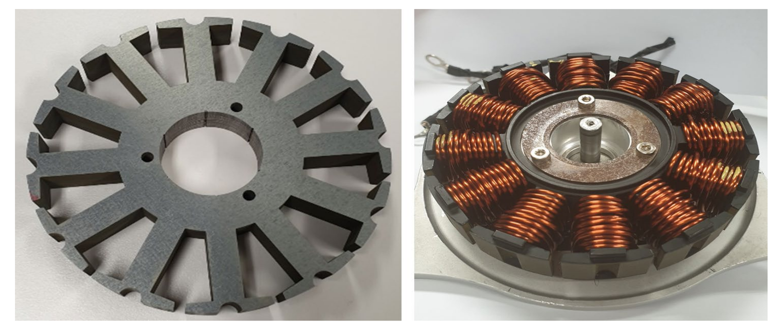

Fig. 6. Notch Model Prototype.

TABLE 4
Comparison of cogging torque simulation data and experimental data

	Simulation	Experiment	Unit
Cogging Torque (Peak to peak)	40.89	40.83	mNm

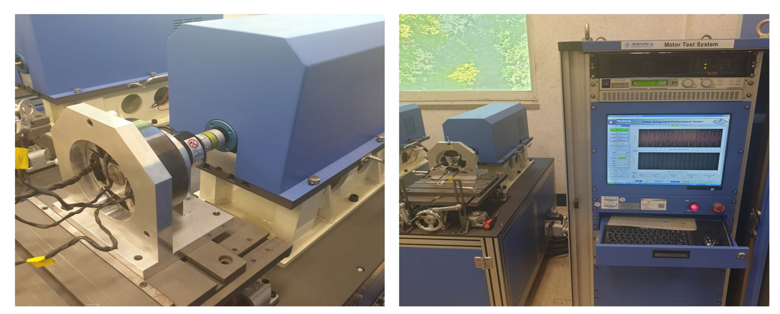

Fig. 7. Dynamo experimental environment.

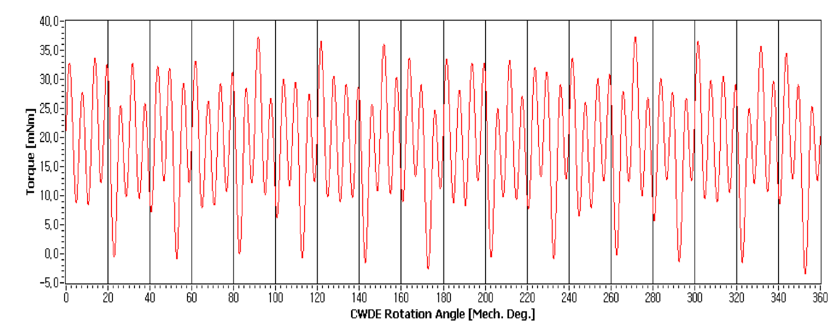

Fig. 8. Notch Model Cogging Torque Measurement Waveform

- Cogging torque is measured using a torque sensor and dynamo at low speeds below 5 RPM with no load.
- Measuring the cogging torque at high speed increases the inertia of the rotor and can be ignored. In addition, at high speeds, it is difficult to measure accurately due to vibration.

Conclusion

In this paper, the cogging torque is improved and optimized by adding a notch to the stator of the outer rotor type surface permanent magnet Brushless DC motor. the nonlinear properties of the magnetic material used in the motor have the nonlinear characteristics, the response surface analysis method used for the nonlinear optimization was optimized. At this time, the large number of notches when having the same output characteristics is disadvantageous in terms of ease of production and cost. The simulation results showed a 12% cogging torque reduction compared to a 2.5% output reduction. After completing the optimal design, the experimental measurement of the prototype showed a 12% reduction to the actual 40.83mNm. Through this paper, the optimum design of stator notch shape of the motor using RSM could be suggested to improve the cogging torque improvement design that minimizes the degra-dation of the motor output characteristics.

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