Optimal Design of Single-Phase Brushless DC Motor for Reducing Cogging Torque

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***Abstract*—This paper performs a stator shape optimization design for reducing cogging torque of single-phase brushless DC motor adopted an asymmetric air gap to make them self-starting. To analyze the characteristic of single-phase brushless DC motor, a time step 2D-finite element analysis (FEA) is carried out. To reduce the cogging torque as well as maintain the efficiency and torque, the Kriging model based on Latin hypercube sampling and Genetic algorithm are utilized. As an optimal design result, cogging torque on the optimal model has been reduced. Finally, the analysis and the optimal design results are confirmed by FEA and experimental results.**

***Index Terms*—Asymmetric air-gap, cogging torque, genetic algorithm, optimal design, single-phase brushless DC motor.**

I. Introduction

Single-phase brushless DC (BLDC) motors are used widely in blower for ventilation system and home appliances because of their high efficiency and cost effectiveness. Single-phase BLDC motors with a uniform air gap make them inherently non-self-starting because they have coincident zero torque positions of excitation. Therefore, single-phase BLDC motors adopt an asymmetric air gap to make them self-starting [1]. On the other hand, such an asymmetric air gap can contribute to the cogging torque [2].

The conventional methods for reducing the cogging torque of single-phase BLDC motors include the length change of the air-gap, PM asymmetry arrangement, skew of the stator or rotor and shape change of the stator teeth. Some papers presented a variation of the air gap profile, considering the tapered teeth and the trailing edge of teeth, to reduce the cogging torque for single-phase BLDC motors [3]. A change in shape of the stator teeth with a notch have been proposed for three-phase BLDC motors [4]. However, a change in shape of stator teeth with asymmetric notches have not been studied for single-phase BLDC motors.

In this paper, a stator shape optimization for single-phase BLDC motor with asymmetric air-gap is performed to reduce the cogging torque as well as maintain the efficiency and torque. To analyze the characteristics of single-phase BLDC motor accurately, a time step 2D-finite element analysis (FEA) is carried out. The Kriging model based on the latin hypercube sampling (LHS) and genetic algorithm (GA) are utilized for optimization of the single-phase BLDC motor with asymmetric notches. An optimal design process is proposed to consider errors between the optimal results by optimization algorithm and verified results of FEA. To confirm the analysis and the optimal design results, the initial and optimal model have been tested and analyzed by FEA, respectively.


(a)


(b)

Fig. 1. Manufactured single-phase BLDC motor (initial model) (a) stator (b) rotor

II. Concept of Cogging Torque Reduction Method for Single-Phase BLDC Motors

Fig. 1 shows the 100W single-phase BLDC motor with 8pole 8slot. BLDC motors with a permanent-magnet inevitably show cogging torque because of the changes caused by the permanent-magnet of rotor and magnetic reluctance of stator core. Equation (1) shows the cogging torque. From equation (1), the rate of change of the magnetic reluctance should be minimized to reduce the cogging torque to the lowest possible.

$$T_{Cogging} = -\frac{1}{2}\phi_g^2 \frac{dR}{d\theta} \tag{1}$$

where, ϕ_g is the air-gap flux, R is the reluctance, and θ is the rotating angle.

In the case of a single-phase BLDC motor with an asymmetric air-gap, the rate of change of the magnetic reluctance is asymmetric according to the rotation of the rotor. Therefore, to reduce the rate of change of the magnetic reluctance under an asymmetric air-gap, the application of an asymmetric notch position to the teeth can reduce the rate of change of the magnetic reluctance. Therefore, size and position of asymmetric notch applied to tapered-teeth are proposed.

III. Optimal Design

A. Optimal Design Process

Fig. 2 shows an optimal design process to optimize effectively the initial model of single-phase BLDC motor.

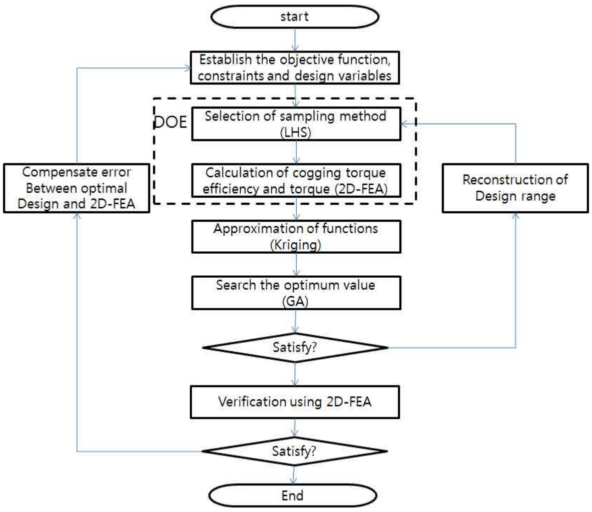

Fig. 2. Flow chart of optimal design process.

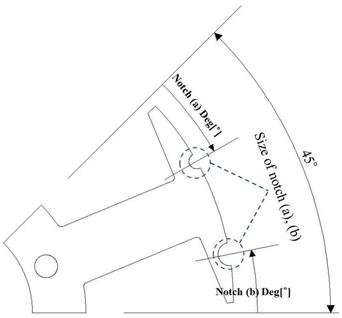

Fig. 3. Optimal design variables of stator

B. *Objective Function, Constraints, and Design Variables*

The objective function is to reduce cogging torque and the constraints are the efficiency and torque on the basis of the initial model, as describe in (2). To satisfy the objective function and the constraints, the design variables are established which are the notch (a) position degree and size (X1, X2), and the notch (b) position degree and size (X3, X4), as shown in (3) and Fig. 3.

- *Objective function*
  Reduce the cogging torque
- *Constraints* (2)
  Efficiency $\geq 75[\%]$
  Torque $\geq 295[\mathrm{N \cdot m}]$
- *Design variables*
  $0 \leq X1$ *(Notch (a) Size)* $\leq 20[°]$
  $0 \leq X2$ *(Notch (a) Degree)* $\leq 1.5[\mathrm{mm}]$ (3)
  $0 \leq X3$ *(Notch (b) Size)* $\leq 20[°]$
  $0 \leq X4$ *(Notch (b) Degree)* $\leq 1.5[\mathrm{mm}]$

C. *Optimal Design Results*

The optimal results using optimization algorithm were almost similar to optimal results verified by 2D-FEA as shown in Table I. Fig. 3 shows the cogging torque from the initial and optimized model. The experiment of initial model is performed to prove the validity of the initial 2D-FE model. Fig. 4 shows

TABLE I
OPTIMAL DESIGN RESULTS OF STATOR OF SINGLE-PHASE BLDC

Item		Unit	Initial model		Optimal model (by optimization algorithm)	Optimal model (verified results by FEA)
			FEA	Experiment		
Design variables	X1	[°]	0		8.502	
	X2	[mm]	0		1.314	
	X3	[°]	0		18.448	
	X4	[mm]	0		0.812	
Cogging torque		[mN·m]	63.27	65.94	39.871	38.625
Efficiency		[%]	76.54	75.43	75.122	75.35
Torque		[N·m]	295.96	296.55	295.582	295.102

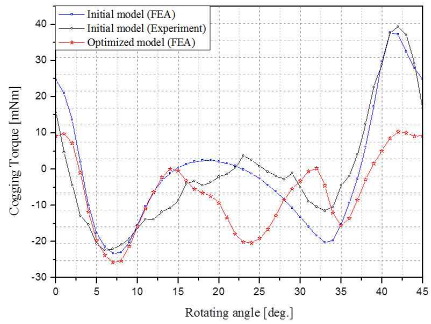

Fig. 4. Results of cogging torque

results of cogging torque. The peak to peak cogging torque of initial 2D-FE model is nearly similar to the result of experiment. The peak to peak cogging torque of the initial and optimized model were 63.27[mNm] and 38.63[mNm], respectively. Therefore, the magnitude of cogging torque of optimized model is reduced more than 46.8% compared to the initial model. More details on the experimental setup and additional results will be presented in the final paper.

IV. CONCLUSION

This paper has performed a stator shape optimization design for reducing cogging torque of single-phase brushless DC motor adopted an asymmetric air gap to make them self-starting. To analyze the characteristic of single-phase brushless DC motor, a time step 2D-finite element analysis (FEA) is carried out. To reduce the cogging torque as well as maintain the efficiency and torque, the optimized algorithms are utilized. As an optimal design result, cogging torque on the optimal model has been reduced as 46.8%.

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