BLDC Motor의 코깅 토크 저감에 관한 연구

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A Study on Cogging Torque Reducing Method of A BLDC Motor

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Abstract - 최근 BLDC 모터는 널리 사용되고 있지만, 불필요한 코깅 토크가 발생된다. 본 논문에서는 BLDC 모터의 코깅 토크 감소 방법을 설계하고 실험 하였다. 이론을 바탕으로 한 이 방법은 모터의 Magnet을 움직여 고주파성분을 제거하여 코깅 토크를 감소시키는 방법이다. 4극 24슬롯 BLDC 모터를 이용하여 Flux2D로 시뮬레이션 하고 계산 결과를 얻었다.

1. Introduction

Brushless permanent-magnet (PM) DC motors are widely used in the industrial applications. They have some good characteristics such as highly efficient, high power-density, easy speed control, low size alternative to conventional machines, low noise and vibration compared with other kinds of motors. But, in these BLDC motors, the main disadvantage is the torque ripple which is inherent in their design. This ripple can lead to mechanical vibration, acoustic noise, and drive system problems. So to minimizing this ripple is very important in designing a PM motor.

One of the major contributors to torque ripples is the cogging torque which is the interaction between the permanent-magnet and the stator slots. Several methods have been proposed to reduce the cogging torque, for example, pole ratio adjustment method, permanent magnet asymmetry arrangement method, semi-closed slots method and a variation of residual magnetization distribution in the PM method.

In this paper, we introduce a method of magnet shifting.

2. Basic Theory

Generally speaking, the cogging torque could be represented by

$$T_c = -\tfrac{1}{2}\Phi_g^2 \frac{dR}{d\alpha} \qquad (1)$$

Where, Φ_g is the flux in air gap; R is the reluctance of air gap and α is the position of the rotor [2]. The equation also proves the idea that cogging torque is the interaction between the magnets (the source of air gap flux) and the stator teeth (the source of air gap reluctance). Because the cogging torque is periodic [3], it can be represented by using Fourier series

$$T_c = \sum_{n=1}^{\infty} T_{mn} \sin(mn\alpha) \qquad (2)$$

Where, m is the least common multiple of stator slot numbers (Ns) and the pole numbers (Np). T_{mn} is the Fourier coefficient [4]. So we can see that the cogging torque has m periods per mechanical revolution of the rotor and has a direct relationship to the pole numbers and slot numbers [8]

Form equation (1), we could make the Φ_g and $\frac{dR}{d\alpha}$ be zero to eliminate the cogging torque. But Φ_g is the alignment and reluctance torque components which drive the motor. So we try to eliminate the $\frac{dR}{d\alpha}$.

Form equation (2) we know that the cogging torque is a summation of harmonic sinusoids. In machines of no cogging torque reduction techniques, the magnets have an additive effect because every magnet has the same relative position with respect to the stator slots [4]. Because the torque from every magnet is in phase, the harmonic components of each are added. So the idea is we can design a machine that the cogging torque coming form each magnet is out of phase, then some of the harmonics can be eliminated and the cogging torque reduces.

How to shift the magnet depends on the pole numbers and slot numbers. In this paper, we only discuss the integer number of slots per pole.

2.1 Integer Number of Slots per Pole

In this kind of machine, each pole has an integer number of slots, so the cogging effects of each magnet are in phase and added [2]. The cogging torque contribution from each magnet is

$$T_{c_p} = \sum_{n=1}^{\infty} T_{pN_s n} \sin(N_s n\alpha) \qquad (3)$$

Where, the $T_{pN_s n}$ is per magnet coefficient. So the total cogging torque is

$$T_c = N_p \sum_{n=1}^{\infty} T_{pN_s n} \sin(N_s n\alpha) \qquad (4)$$

Because each pole has an integer number of slots, the least common multiple of pole numbers and slot numbers in such motors is the slot number Ns. The equation (4) actually is the same as equation (2) if we rewrite it like this

$$T_c = \sum_{n=1}^{\infty} T_{N_s n} \sin(N_s n\alpha) \qquad (5)$$

The Ns is the least common multiple m.

Now we shift the magnet, and each magnet is shifted with respect to the others. Then the total cogging torque of shifted motor is

$$T_c = \sum_{k=0}^{N_p-1}\sum_{n=1}^{\infty} T_{pN_s n}\sin(N_s n(\alpha - k\alpha_0)) \quad (6)$$

Equation (6) is same as equation (4), in equation (6), α_0 is the angle that each magnet is shifted with respect to the others. For the highest harmonic cancellation, α_0 is

$$\alpha_0 = \frac{2\pi}{N_s N_p} \quad (7)$$

Calculating the equation (6) we can get that now the cogging torque is

$$T_c = \sum_{n=1}^{\infty} T_{N_s N_p n}\sin(N_s N_p n\alpha) \quad (8)$$

We cancel all the harmonics except multiples of the N_p^{th} , so the cogging torque is reduced.

3. Calculation

We calculate the cogging torque by using Flux 2D. In this paper we take an 4 poles 24 slots BLDC motor as an example. The least common multiple is 24, each magnet is in phase ,so According to the equation (7), magnet 1 is in the initial position, magnet 2 is shifted 3.75° counterclockwise, magnet 3 is shifted 7.5° counterclockwise, magnet 4 is shifted 11.25° counterclockwise. The Fig. 1 is the initial motor; Fig. 2 is the motor with shifting magnet. According to the equation (7), magnet 1 is in the initial position, magnet 2 is shifted 3.75° counterclockwise, magnet 3 is shifted 7.5° counterclockwise, magnet 4 is shifted 11.25° counterclockwise.

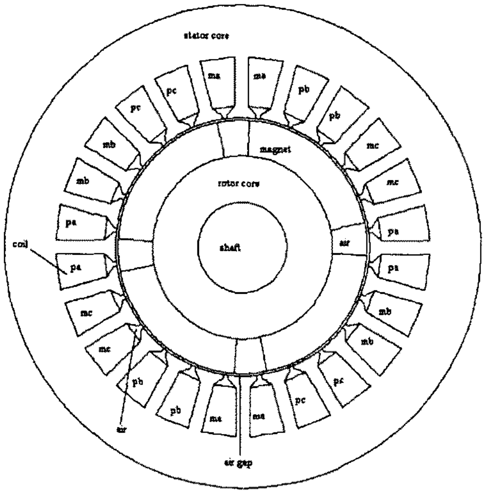

Fig. 1 Structure of initial motor

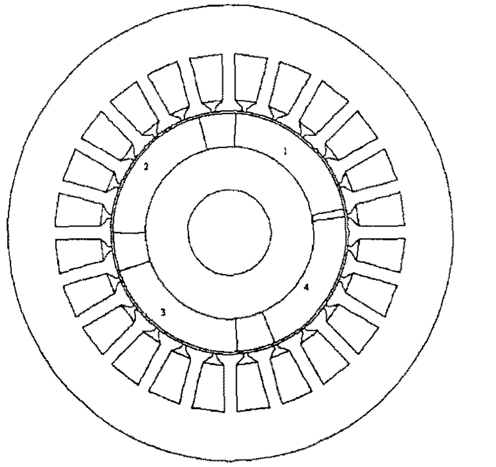

Fig. 2 Structure of magnet shifted motor

The flux line in shown in the following Fig. 3 and Fig. 4.

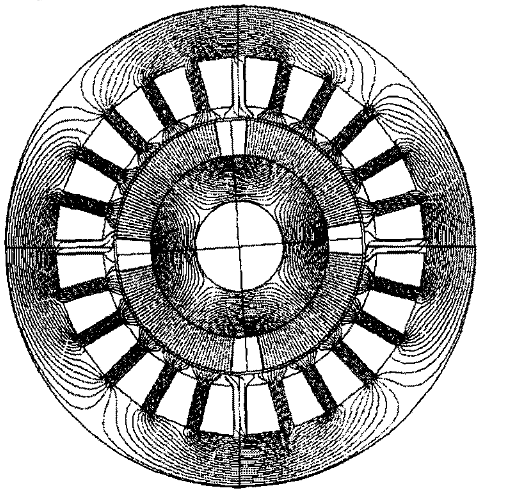

Fig.3 Flux line of initial motor

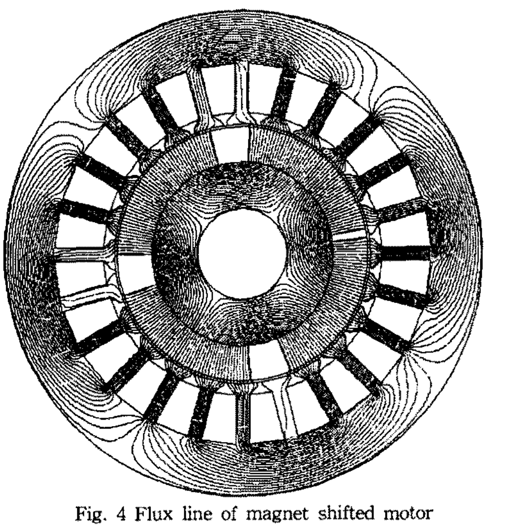

Fig. 4 Flux line of magnet shifted motor

The cogging torque is shown in Fig. 5 and Fig. 6

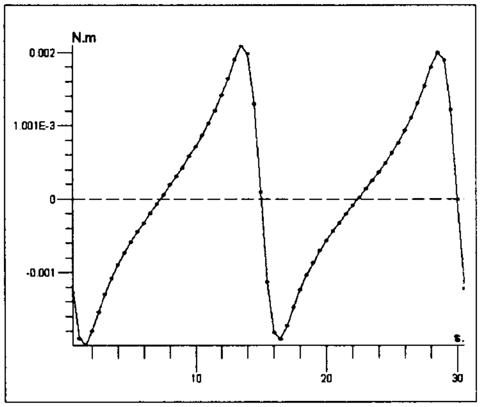

Fig. 5 Cogging torque of initial motor

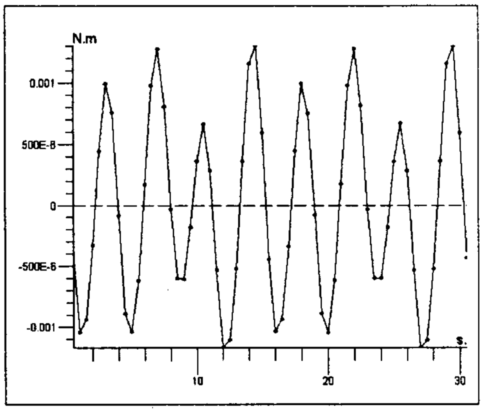

Fig. 6 Cogging torque of magnet shifted motor

We can see that the magnitude of cogging torque in Fig. 5 is 0.00408575 N.m, which is reduced to 0.00247067 N.m in Fig. 6. The cogging torque is reduced 39.5%

4. Conclusion

This paper introduces a method of reducing the cogging torque of Brushless DC PM Motor by shifting the magnet of the motor. The results prove the theory and the cogging torque is reduced much. Because we shift the magnet, the center of gravity shifts, too. This cause some mechanical vibration problem, but it is very small and we do not consider it in this paper.

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