Design of High Torque Brushless DC Motor considering Winding coefficicent

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Abstract

In this study, brushless DC motor with high torque and power density is proposed and manufactured. Concentrated windings which are suitable for small space and high efficiency system are applied to the proposed motor considering winding coefficient. Electromagnetic design is executed by equivalent magnetic circuit model and numerical analysis. Manufactured motor is tested and verified the characteristics of high winding coefficient.

1 Introduction

As permanent magnet machines are getting great interest in driving system, design method to increase output torque and power in limited volume is one of the main issues in motor design. With concentrated windings, the volume of copper used in the end-windings can be reduced and a significant reduction of the Joule losses is achieved, and the efficiency of the motor is improved. In this study, the combination of pole and slot number is considered to increase torque constant and efficiency. Winding coefficient with respect to various pole/slot combinations is analyzed and the best one is selected. The designed motor is manufactured and tested.

2 Winding coefficient

The pole/slot ratio affects winding coefficient and the factor is related to torque constant. Therefore, pole and slot number should be determined considering manufacturing capabilities, winding coefficient, and iron loss. Distributed winding has a merit to increase winding coefficient (maximum 1), however, end turn part can be obstacle for reducing copper loss and overall axial length of motor. Table 1 shows the winding coefficient according to the pole/slot combinations [1]. The winding coefficient K_w is induced by

$$K_w = K_d K_p \tag{1}$$

which K_d and K_p are distribution coefficient and pitch coefficient, respectively and skew factor is neglected. The distribution coefficient K_d reflects the fact that the winding coils of each phase are distributed in a number of slots. Since the EMF induced in different slots are not in phase, their phasor sum is less than their numerical sum. The pitch coefficient K_p reflects the fact that windings are often not fully pitched, i.e. the individual turns are reduced in order to decrease the length of the end-turns and do not cover a full pole-pitch. As can be seen in Table 1, if the pole/slot ratio are 10/12, 14/12, the maximum winding coefficient of 0.966 can be obtained. The second and third maximum values are gained when the pole/slot ratio are 8/9, 10/9, 14/15, whose values are 0.951, 0.945. However, the winding coefficient of 0.966 is gained when the number of winding layer is one. In the case of two layers, the winding coefficient is reduced to 0.933. Also, in previous studies, pole/slot combinations of slot number= 9+6k, k = 0,1,2…and pole number = slot number ± 1 have non- symmetrical distribution of the magnetic forces on the stator [2]. The sum of these magnetic forces gives a resulting force that turns around with the time and generates noise and vibration in the machine. We choose pole/slot ratio of 10/12 with two winding layer considering driving frequency and shorter axial length of stator. Although the winding coefficient is a little bit less than that of the one winding layer, the end-turn parts of stator and noise/vibration are reduced.

Table1: Winding coefficients as a function of the number of slots (S) and poles (P)

S \ P	2	4	6	8	10	12	14
3	0.866	0.866		0.866	0.866		0.866
6		0.866		0.866	0.500		0.500
9			0.866	0.945	0.945	0.866	0.617
12				0.866	0.966		0.966
15					0.866		0.951
18						0.866	0.902
21							0.866

3 Back EMF constant

The fundamental object of design process is to determine the back EMF (Electromagnetic Force) of motor, so air gap flux density calculation is required in the first step. In this study, magnetic circuit model is used to compute design parameters and finite element analysis is applied to confirm the results and execute specific design. Fig. 1 shows the magnetic circuit of motor. The air gap flux from the circuit can be written as

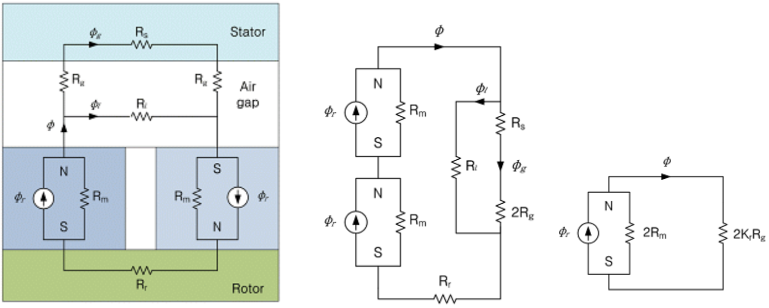

Figure 1: Magnetic circuit model

$$\Phi_g = K_l\Phi = \frac{K_l}{1+K_r\dfrac{\mu_r g A_m}{l_m A_g}}\Phi_r \tag{2}$$

where A_m, l_m and A_g, g are magnet and air gap cross-section area, length, respectively, Φ_r is flux source, K_l is the flux leakage factor, K_r is reluctance factor which increases air gap reluctance slightly to compensate for the missing steel reluctance[3]. Considering the flux linkage waveform which varies from a maximum positive value Φ to a maximum negative value $-\Phi$, back EMF over half an electric cycle is given by

$$E = \frac{d\lambda}{dt} = \omega_e\frac{d\lambda}{d\theta_e} = p\omega_m\frac{2N\Phi_g}{\pi a} = K_e\omega_m \tag{3}$$

where λ is flux linkage and p is pole pair number, N is the number of conductors per phase, and a is the number of parallel paths. Using the winding coefficient K_w, the back EMF constant K_e can be expressed as

$$K_e = \frac{2pN\Phi_g K_w}{\pi a} \tag{4}$$

Through the determined parameters including applied voltage and coil resistance, output characteristics with respect to loading torque are estimated.

4 Measurement

Fig. 2 shows manufacturing stator and rotor of the designed motor. The split core is applied to the proposed motor for increasing coil fill factor and parallel magnetized permanent magnet is attached to the surface of rotor core keeping constant gap. For the loading torque test, the motor is connected to torque measuring system and sensorless BLDC (Brushless DC) amplifier is used to drive the proposed motor. No load speed is about 7,000rpm and maximum efficiency is 89%, and at the rated condition of 150W, rotational speed, torque, and efficiency are 6,000rpm, 240mNm, and 88%, respectively.

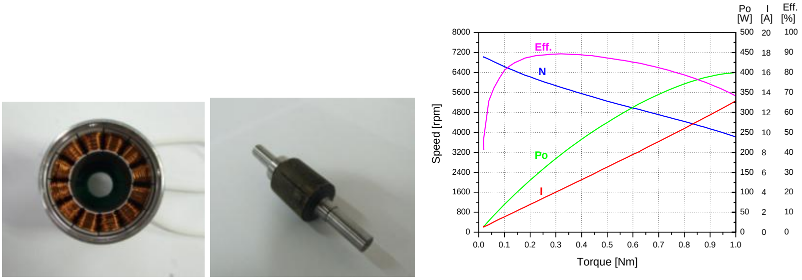

Figure 2: Manufactured motor and input/output characteristics of motor

5 Conclusion

Concentrated windings are applied to the proposed BLDC motor considering winding coefficient. By using equivalent magnetic circuit and finite element model, characteristics of the motor is analyzed.

References:

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