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Design and Performance Analysis of a Novel Two Phase BLDC Machine with Thin Magnets Avoiding Demagnetization

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영구자석 감자를 피하기 위한 새로운 2상 BLDC 전동기의 설계 및 특성 해석

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Abstract - This paper presents a novel design and performance analysis of two phase brushless DC motor (TPBDCM) by operating motor in only magnetization (pull) process and avoiding demagnetization (push) process of magnets in the machine. Normally, permanent magnet machines operate in both magnetization (pull) and demagnetization (push) process of magnets. In certain events, permanent magnets (PM) may go to irreversible demagnetization to fail the motor operation. So, thick magnets are used to avoid the demagnetization of magnets. However, modern commercialized rare earth magnets used in electrical machines have significant cost of permanent magnet machines. Thus, this is valuable to be accomplished using very thin rare earth magnets in TPBDCM, which reduces the effective airgap length, the magnet volume as well as the cost of motor with same characteristics achieved at the expense of current density. FEM analysis is performed and compared with a conventional two phase machine.

1. Introduction

Due to their high performance characteristics such as higher power density, low maintenance cost and high reliability, brushless permanent motors have wide applications such as industrial automation, in aerospace, traction and medical applications. Two phase brushless DC motors are more efficient and have low torque ripples than the single phase PM motor. In construction, brushless DC motors (BDCM) have permanent magnets on rotor and wound stator. The permanent magnets (PM) used in BDCM are mainly subjected to demagnetization due to some internal and external demagnetizing fields. These fields act against the permeance of the magnets making magneto-motive force (mmf) distribution asymmetric [1]. This causes the unequal flow of magnetic flux, in turns, disturbing the operation of motor. Many researches have been carried out on the phenomenon of demagnetization and effects of demagnetization of magnets in PM motors due to internal and external forces. Irreversible demagnetization of permanent magnets due to the armature reaction has also been analyzed [3]. The authors in [4] have presented the risks of irreversible demagnetization caused by the large transient fault currents. Rotor configurations of permanent magnet synchronous motors are given to protect the magnets from demagnetization [5]. The authors in [6] have presented the reduction of eddy current loss in PM to prevent demagnetization of PMs.

In this paper, a novel topology of two phase brushless DC motor (TPBDCM) is designed such that to keep only pull process and eliminating push process. Demagnetization can be avoided by this kind of only pull operation. Thus, the proposed machine can be designed by using very thin magnets. Therefore, the magnet thickness and machine price are significantly reduced and the proposed machine is prevented from demagnetization due to only pull operation.

Basic operation principle of TPBDCM is given in section-II. Design principle is introduced in section-III. Finally, methodology and performance analysis have been presented in section-IV.

2. Basic Operation Principle

The basic pull process for TPBDCM and basic demagnetization curve are shown in Fig. 1. When rotor is rotated, magnetic flux linkage changes due to reluctance. Thus torque produced has two components: reluctance torque and alignment torque. When rotor pole begins to overlap with stator pole of one phase until pole pair fully aligns, flux linkage linearly increased called pull process (magnetization). Similarly, when the rotor pole leaves fully aligned position until there is no overlapping between the poles, then flux linkage decrease linearly called push process (demagnetization).

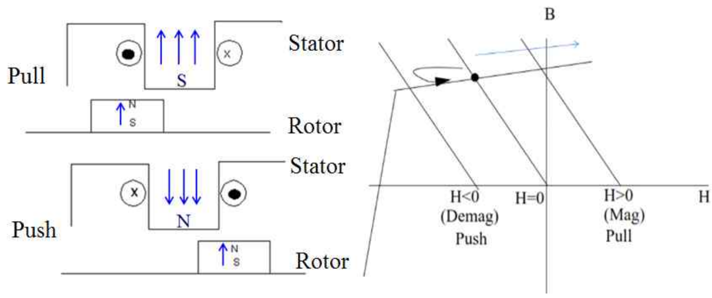

Fig. 1 Basic operation principle of only pull process

In operation, current is applied for half of the time and making rest part of current equal to zero. When the current is injected, net flux is sum of flux from permanent magnets and induced stator current. Since the flux linkage distribution is only approximately linear, the back-EMF distribution shown in Fig. 2 is ideal. Thus torque is produced by one phase at a time. The resultant output torque will be from alternate conduction of two phases. Then flux linkage of armature winding and torque by two phases A and B is shown, where 'a' shows torque from phase A and 'b' shows torque from phase B.

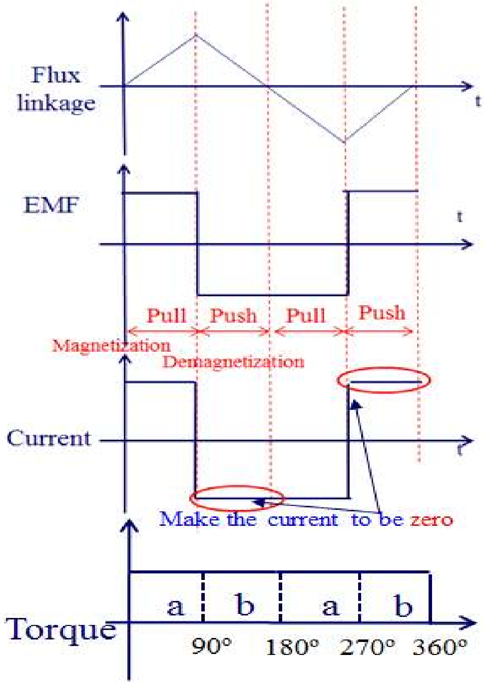

Fig.2. Relationship between input and output parameters

3. Design Principle

The basic configuration of the conventional and proposed TPBDCM are shown in Fig. 3. The proposed machine has radially magnetized magnets on the rotor and wound stator having phase group winding configuration. TPBDCM is designed for only pull process but following no-push process.

Design of TPBDCM has following features:

1. The width of the stator teeth is equal to the width of the stator slots at the air gap
2. The width of the magnets is equal to the width of the stator teeth
3. There is an extra spacing of 90 electrical degrees between the phase belt of phase 'a' and phase 'b'

$$\theta_e = p\ \theta_m \qquad (1)$$

4. All of the magnets are pulling at the same time for one phase
5. All of the phase 'a' magnets are pulling for 1/2 slot pitch with current applied to phase 'a' while the current in phase 'b' is zero. Then all of the phase 'b' magnets are pulling for 1/2 slot pitch with current in phase 'b' is current in phase 'a' is zero. The only-pull process with respect to rotor position for TPBDCM is shown in fig.4.

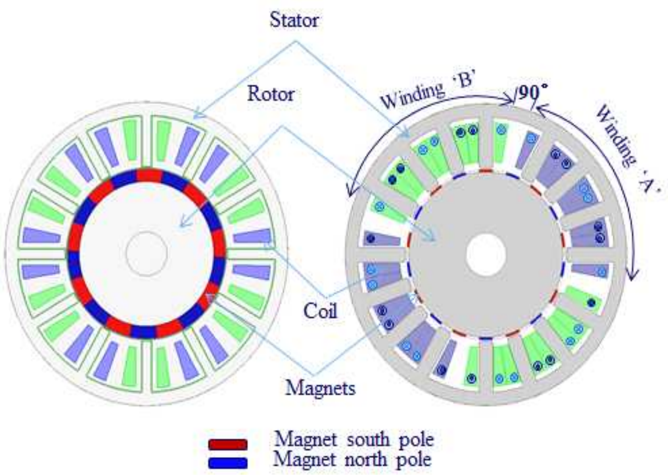

Fig.3. Two phase brushless DC machine (a) conventional machine, 12slot/18pole (b) proposed machine, 16slots/18pole

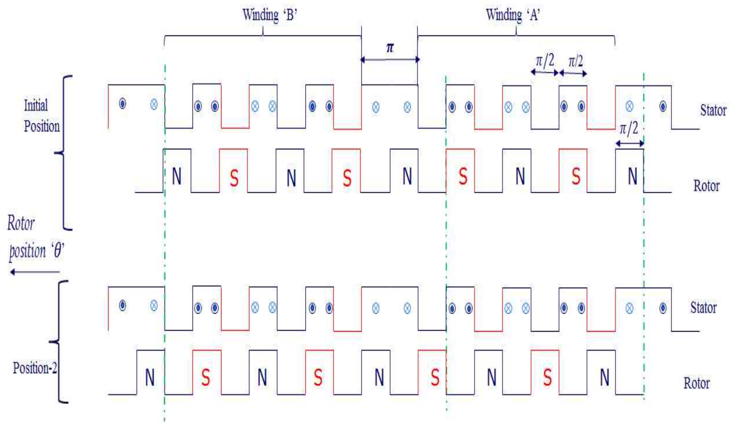

Fig.4. Pull process and rotor position

The no. of slots at stator and no. of magnet poles can be selected as [7]

$$2P=2n_1n_2+n_2 \qquad (2)$$

where, $2P=N_m=$ no. of magnet poles on rotor, Ns = no. of stator slots $=2n_1n_2$, n_1 is defined as the number of coils for one phase group, n_2 is the number of groups for one phase

$$2P=N_s+n_2$$

For $n_1=4$ and $n_2=2$, 16-slots and 18 rotor pole two phase machine is investigated. The design specification is given in Table.1 as below. A conventional 12-slot and 18-rotor pole machine based on a product from SN-tech company selected for comparison with a same overall volume.

Table.1. Design specification for proposed TPBDCM

Item		Unit	Value
Output Power		W	1170
Rated speed		rpm	1580
Rated torque		Nm	7.29
Number of slots		-	16
Stack length		mm	90
Number of poles		-	18
Air gap length		mm	0.7
Permanent Magnets	Br	T	1.14
	Hc	kA/m	-868

4. Methodology and Performance Analysis

As performance of BDCM mainly depends upon power, torque and operating point of magnets on rotor. Low cogging torque is also a key for better performance to avoid the noise and vibration in the machine. Output torque is proportional to current density at armature. In order to minimize the cogging torque of machine, stator teeth edges and rotor magnet pole arcs are chosen as round shape at corners. Rare earth neodymium (NdFeb) magnets with properties, Br=1.14 and Hc=-868 kA/m are used for rotor poles. Operating point of magnets can be determined by energy product $(BH)_{max}$. Higher the energy product, lower demagnetization will occur. The proposed machine have a less torque produced due to only pull operation, thus, the input current is increased to obtain the same torque characteristics with the conventional machine. In other terms, input current to the armature windings will be high at the cost of reducing the thickness of magnets on rotors. Also lower the magnet thickness, lower will be cogging torque to achieve better performance [8].

The proposed model with 16 slots and 18 rotor poles with very thin magnets as thickness of ‘1 mm’ is analyzed. The results are compared with a conventional model with 12 slots and 18 rotor poles with magnets thickness of ‘6 mm’. The mechanical airgap is kept same (0.7 mm) for both models but equivalent airgap is decreased in proposed model due to less magnet thickness. The conventional model operates in both magnetization and demagnetization process in normal condition. The proposed model is operated in only pull process in which magnets are magnetized only and does not go the demagnetization (push) process. This is achieved controlling the motor operation in one phase conduction mode. when phase ‘A’ is energized for 90 degree, all the magnets are pulled only for half of the slot pitch and phase ‘B’ remains non-energized. Similarly, when phase ‘B’ is energized, the magnets are pulled again for half slot pitch for one phase. In this operation at the same current density, torque of machine is reduced to half. To achieve the same torque as that of conventional machine, applied armature current in the proposed machine is increased to almost double in magnitude without demagnetization and saturation.

Input current to two phase BLDC machine is fed through drive circuit with PWM using Ansys Simplorer tool co-simulation with Ansys Maxwell. One phase operation is conducted for 90 degree commutation period.

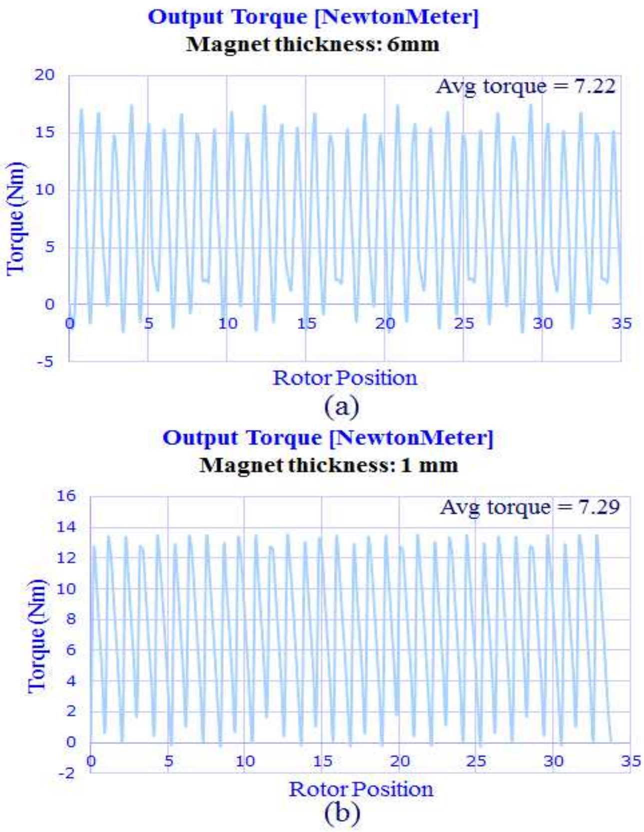

Fig.6. Output Torque (a) for conventional model (b) for proposed model

Finite element analysis is used to validate the torque performance at the cost of current density. Fig.6 (a) shows the torque curve for the conventional machine and Fig.6 (b) shows the torque curve for the proposed TPBDCM. From the comparison, average torque is noted. This is obvious that the output torque characteristics are same for both models.

5. Conclusion

This paper has proposed the novel two phase brushless dc machine. Very thin magnets with thickness of ‘1 mm’ are used on rotor to reduce the size as well as cost of TPBDCM. Performance analysis is compared with conventional two phase machine. Based on finite element analysis, it is proposed that with using very thin magnets it is possible to obtain the same torque characteristics but at the expense of current density in armature. This is also described that demagnetization can be avoided using proposed topology while operating two phase machine in only-pull mode. Adopting this method, the cost of the PM machine can be saved by magnet thickness reduction to achieve an adequate performance.

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