International Journal of Electronic and Electrical Engineering.
ISSN 0974-2174 Volume 7, Number 10 (2014), pp. 1077-1082
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Effect of Skewing on Performance of Radial Flux Permanent Magnet Brushless DC Motor

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Abstract

In this paper the effect of skewing on performance of a 200W, 24V, 1000 rpm surface mounted radial-flux permanent magnet brushless dc (SPM BLDC) motor is analyzed and presented. The 2D Finite element analysis (FEA) results are exploited for the analysis of effects of skewing on torque ripple, torque profile and average torque. The percentage torque ripple is reduced considerably due to skewing of rotor. The average torque increases slightly and gets the smooth torque profile due to the skewing of rotor.

Keywords: Radial-flux permanent magnet brushless dc (PM BLDC), Computer Aided Design (CAD), Finite Element Analysis (FEA).

I. Introduction

Permanent Magnet Brushless DC (PMBLDC) motors are increasingly becoming popular in various industrial and domestic applications due to their high efficiency and power density. High speed permanent magnet brushless dc motors are emerging as a key technology for applications such as spindle drives, compressors, pumps, gas turbine micro generators and electric hybrid vehicle systems. They are usually more efficient because fields copper losses are entirely eliminated and copper losses in general are reduced compared to conventional machines. Due to lower losses, heating of PMBLDC motor is less, due to which it can result either run at low temperature and or to and it increases shaft power so that maximum allowable temperature can be reached.

Generally, most PM motors are of radial flux type. Axial flux PM machines applications are still considered as niche hence focus of this paper will be on radial flux permanent magnet brushless dc motors since these constitute the majority of brushless PM motors. The design of PM motor requires iterative computations. Designer needs to assume certain variables based on requirement of specific application and availability of material. The computer aided design (CAD) program is developed for the design and performance estimation of permanent magnet brushless dc motors. Outcome of CAD program is used as input for finite element analysis (FEA). Cogging torque is the alignment torque between stator teeth and rotor magnet and is most prominent in surface magnet type permanent magnet brushless dc motors. There are specific approached to reduce cogging torque and improve torque profile. Effect of skewing of rotor is analyzed using two dimensional (2-D) FEA.

II. Design Consideration and Computer Aided Design of PMBLDC Motor

Air gap flux density pattern

Magnetization pattern as well as shape of the Permanent Magnets influences the air-gap flux density pattern. They have substantial influence on cogging torque and in turn on torque ripple.

***Permanent Magnet (PM)* material**

Magnet is integral part of the motor so mechanical and electrical properties are required to be considered. Nd-Fe-B and samarium cobalt permanent magnets are preferred because of their high-energy product (BH_{max}) and retentivity (B_r). The selection depends on the cost and performance requirement. Nd-Fe-B magnetic material is selected here[1].

Specific loadings

Specific magnetic loading depends on type of permanent magnet properties. Specific current loading depends on efficiency and permissible temperature rise.

Winding configuration

Both amplitude and shape of the back EMF and the stator MMFs in these machines are determined by the winding arrangements and general machine geometry. Winding factor depends on pitch factor, distribution factor and skew factor. Normally stacking factor of 0.9 is considered for 29 gauge laminations.

Length of air gap

Phase inductance, armature reaction and cogging torque reduce with increment in length of air gap.

Stator slot shape

It is very essential to select proper shape of stator slot in order to improve torque profile. It will be resulted in to lower torque ripple. Torque ripple plays significant role when speed is low.

Skewing of Rotor

In this paper surface mounted Permanent Magnet rotor is considered. Nd-Fe-B permanent magnet material is used. Stainless steel grade 416 is used for rotor core. Skewing is done to minimize cogging torque.

Computer Aided Design (CAD) program is developed for surface mounted Permanent Magnet Brushless DC motor. This CAD Program consists of four main design stages.

- Main dimension calculation
- Stator design
- Permanent Magnet rotor design
- Performance calculation

The CAD program has two decision making loops. The outer loop is used for correction of efficiency and inner loop is used for flux density. Decision making loops will be active till the error between assumed quantities and actual quantities is within the acceptable limit. Electrical and Mechanical performance depends on geometry and selection of material.

III. Skewing of Radial Flux Permanent Magnet Brushless DC Motor

CAD is carried out for the 200 W, 1000 rpm, 24 V surface mounted radial flux Permanent Magnet Brushless DC motor for the no-load and full load conditions. FE analysis is carried out based on the results obtain from CAD program. Without skewing 1.89 Nm. average torque is obtained, with a torque ripple of 63% in FE analysis. As per CAD algorithm average torque is 1.94 Nm. Results from FE analysis and CAD algorithm are fairly matching. Torque ripple is defined as difference between maximum torque and minimum torque expressed as percentage of average torque.

$$\%_{ripple} = \frac{T_{\max} - T_{\min}}{T_{\text{avg}}} \times 100$$

In order to improve the performance of motor it is highly desirable to reduce torque ripple. Magnetic circuit analysis is required to reduce torque ripple. The actual torque profile obtained from FE analysis without skewing and with skewing is shown in figure 4. In this design magnet arc angle is 57^{o}. So the magnet gap angle is 33^{o} as shown in figure1. In case of the radial-flux surface mounted PMBLDC motors, skewing of rotor poles is a viable and effective method for the torque ripple minimization. Here 2D FE analysis is carried out by skewing the magnet angle in small steps by maintaining the stator slot in initial position itself and obtaining the torque profile for each step and then finally adding the torque profiles of all the steps to get the torque profile of the motor with the rotor poles skewing.

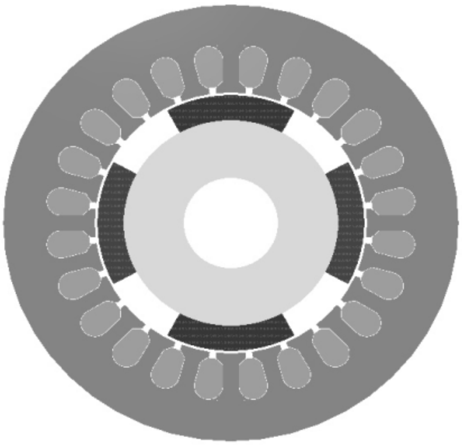

Fig1. 0° Skewing in 200 W radial flux PMBLDC motor.

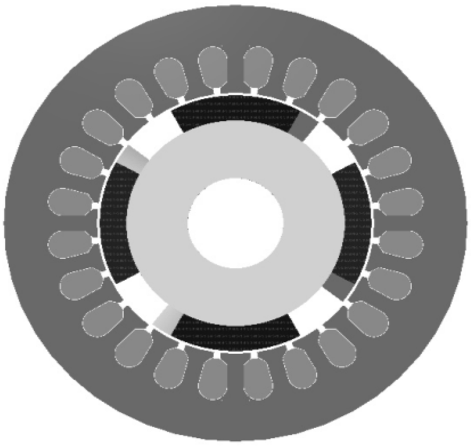

Fig 2. 10° Skewing in 200 W radial flux PMBLDC motor.

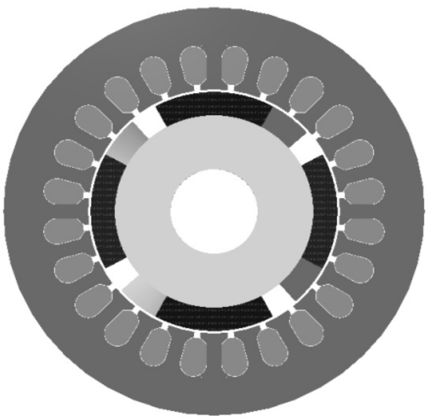

Fig3. 20° Skewing in 200 W radial flux PMBLDC motor.

By performing FE analysis at 10° skewing the average torque is obtained 1.98 Nm. At 20° skewing average torque is obtained 2 Nm and at without skewing the average torque is obtained 1.89 Nm. By comparing all these value of the average torque at 20° skewing is higher than the 10° and 0° skewing respectively.

The torque profile of the motor with two different skew angles in rotor poles, with skew angle equal to 0° and with the skew angle equal to a 10° and 20° are given in figure 4. The average torque and the ripple torque in each case is worked out and given in table-1.

It can be observed that the skewing reduces the torque ripple, but also increases the average torque. For a 20° skewing in rotor poles, torque ripple is 40%, and average torque also increases at 5.82%. With 10° skewing, the torque ripple is also 40%, but the increased average torque is only 1.01%.

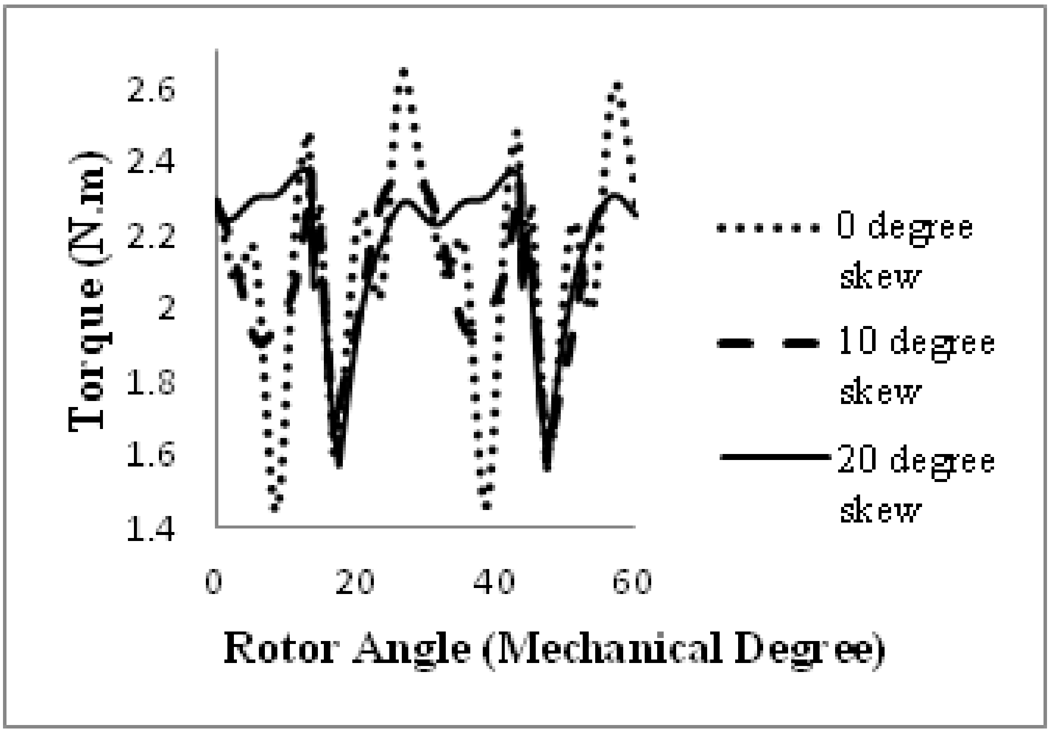

Fig4. Torque profiles of designed 200 W radial flux surface mounted PMBLDC motor with skewing in rotor poles.

TABLE I Results for 200 W, 24 V, 1000 rpm model without skewing

Parameters	FE analysis result
Torque (Nm)	1.89 Nm
Input Power (kW)	0.239 kW
Output Power (kW)	0.200 kW
Torque per unit volume (Nm/mm^2)	1.85E-05
Efficiency (%)	83.7%
Supply Current (A)	9.95 A

TABLE II Average Torque and Torque ripple for different skew angle in a 200 W, 24 V, 1000 rpm Radial Flux Surface Mounted PM BLDC motor from FE analysis.

SKEW ANGLE	0^0	10^0	20^0
AVERAGE TORQUE (Nm)	1.89	1.98	2.0
PERCENTAGE TORQUE RIPPLE	63%	40%	40%

IV. Conclusion

From analysis it is concluded that the skewing of rotor is effective technique to reduce torque ripple of Radial Flux Permanent Magnet Brushless DC motor. 1.89 Nm average torque is obtained without skewing and 2.0 Nm average torque is obtained with 20° of rotor skewing. Parallely torque ripple is reduced from 63% to 40% due to 20° skewing of the rotor.

V. References

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