INFLUENCE OF MAGNET POLE ARC VARIATION ON THE COGGING TORQUE OF RADIAL FLUX PERMANENT MAGNET BRUSHLESS DC (PMBLDC) MOTOR

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Abstract— Permanent magnet brushless dc (PMBLDC) motors are increasingly used in various industrial and domestic applications due to certain advantages over conventional motors like high efficiency, compactness, no excitation losses, high torque-to-current ratio. In many of applications cogging torque is a primary concern because it creates vibrations and noise. In this paper influence of magnet pole arc variation on the cogging torque of three standard rating of Radial Flux Permanent Magnet Brushless DC Motors is analyzed. Permanent magnet rotor pole arc is varied from 62 degree to 54 degree, while the number of rotor poles and number of stator slots are kept same for all three standard ratings. It is observed that the cogging torque is influenced by magnet pole arc variation. Hence, it is very essential to select proper permanent magnet rotor pole arc to reduce the cogging torque in order to improve the performance.

Index Terms— Radial Flux Permanent Magnet Brushless dc Motor (RFPMBLDC), Permanent Magnet (PM), Finite Element Analysis (FEA), Cogging Torque

I. INTRODUCTION

Radial Flux Permanent Magnet Brushless DC (RFPMBLDC) motors have found numerous applications due to their advantages like, high efficiency, compact structure, high torque-to-current, high torque-to-volume ratio and fast dynamic response, as opposed to conventional motors[3][4]. Due to the absence of gear mechanism, it is most preferred choice in hybrid electrical vehicles as the overall weight of vehicle reduces and efficiency improves. One major drawback of PM machines is high cogging torque. Cogging torque is the interaction between the tip of the permanent magnets and the stator tooth. It is caused by an uneven air-gap permeance resulting in the magnets constantly seeking a position of minimum reluctance [5]. A large number of PMBLDC applications require minimum cogging torque for reduced vibration and noise and smooth operation of the motor. For such applications, torque quality becomes exceptionally significant, and motor design and analysis must be finalized paying attention to cogging torque. CAD and Finite Element Analysis (FEA) is done for three standard ratings (i) 200 W, 24 V, 1000 rpm (ii) 746 W, 230 V, 2000 rpm and (iii) 2.2 kW, 230 V, 1450 rpm. Number of rotor poles are 4 and number of stator slots are 24 for all three standard rating selected. FEA is done to analyze the effect of permanent magnet rotor pole arc variation on cogging torque. Cogging torque can be significantly reduced by optimum selection of magnet pole arc.

II. DESIGN OF RADIAL FLUX PMBLDC MOTOR

Design of Radial Flux Permanent Magnet Brushless DC motor can be intensive due to the requirement of many design constraints. There are four main steps for design:

A .Main Dimensions
B. Stator Design
C. Rotor Design
D. Performance Estimation

A. Main Dimensions

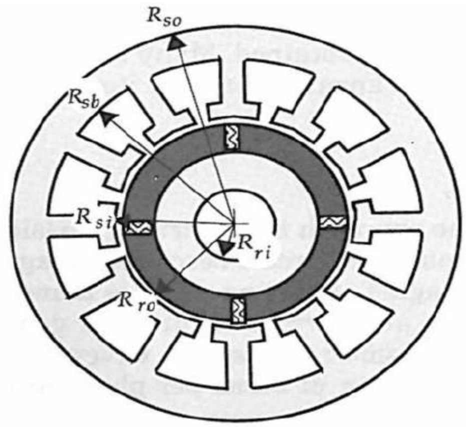

Figure 1 Main dimensions of Radial Flux (PMBLDC) Motor

Axial length(L), Rotor outer diameter(D_{ro}) and Stator outer diameter(D_{so}) are the main dimensions of the RF PMBLDC motor. These main dimensions are calculated based on assumption of various design variables.

B. Stator Design
Stator back iron width, slot depth, slot area, tooth width, slot opening are the major dimensions of the stator [1]. Dimensions of the magnetic circuit are calculated based on maximum permissible flux density of magnetic material.

C. Rotor Design
Selection of number of rotor poles in permanent magnet brushless dc (PMBLDC) motor depends upon factors like speed of rotation, cost, availability of PM, iron loss, interior rotor or exterior rotor [2]. It is very essential to select proper number of rotor poles to achieve good quality of torque profile. Neodymium-Iron-Boron (NdFeB) is having highest energy product and highest residual flux density among all the permanent magnetic materials. Range of length of air gap for RFPMBLDC motor is 0.5 to 2 mm.

D. Performance Estimation
It is very essential to estimate the performance based on design information. The performance estimation is carried out to check efficiency, temperature rise and actual flux density. If objectives are not met, modifications have to be made.

III. INFLUENCE OF ROTOR POLE ARC VARIATION ON COGGING TORQUE

Cogging torque is generated by the interaction between the magnet edges and the stator teeth. Cogging torque can be reduced by proper selection of rotor permanent magnet arc as peak to peak value and shape of the cogging profile depends on the magnet pole arc and on the physical geometry of the magnet [6]. In its most fundamental form, cogging torque can be represented by,

$$T_{cog} = -\frac{1}{2}\phi_g \frac{dR}{d\theta} \quad (1)$$

Where,
ϕ_g = Air gap flux
R =Air-gap reluctance
θ = Rotor position
The air-gap reluctance varies periodically, thus causing the cogging torque to be periodic. Cogging torque can be minimized by making the $\frac{dR}{d\theta}$ equals to zero. It can be represent as a Fourier series[5].

$$T_{cog} = \sum_{k=1}^{\infty} T_{mk} \sin(\mathrm{nk}\,\theta) \quad (2)$$

Where,
$\mathrm{n} = \mathrm{LCM}(N_s, N_p)$
k = An integer
T_{mk} = Fourier coefficient
Number of rotor poles and stator teeth has significant effect on cogging torque.

[A] Cogging Torque Analysis for 200 W, 24 V, 1000 rpm Radial Flux PMBLDC Motor

Fig.2 shows the FEA model for 200 W, 24 V, 1000 rpm radial flux PMBLDC motor with magnet pole arc of 58 degree. The magnet pole arc is varied from 62 to 54 degree and cogging torque profile is obtained. The cogging torque for the same motor is shown in Fig 3. Peak to peak cogging torque is influenced by variation of magnet pole arc. Minimum peak to peak cogging torque is observed when magnet pole arc is 58 degree. From the results shown in table 2, it is concluded that by reducing magnet pole arc from 62 degree to 58 degree, reduction in cogging torque is from 0.89 Nm to 0.34 Nm, which is 61.7% reduction from original design. Further reduction in magnet pole arc is not advisable, as it will again increase the cogging torque. Magnet pole arc with 58 degree give the best results in terms of cogging torque.

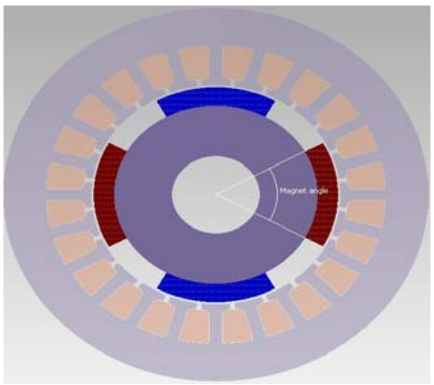

Figure 2 Pole arc 58 (degree)

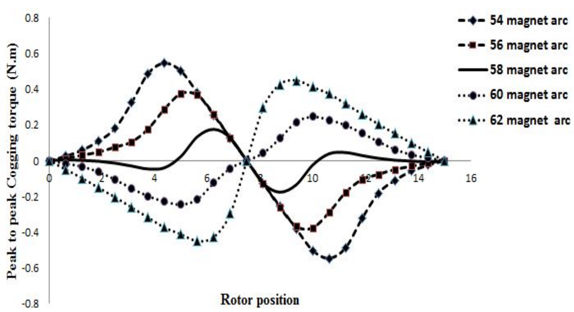

Figure 3 Cogging torque profile of 200 W Motor

Table I
PEAK TO PEAK COGGING TORQUE FOR 200 W, 24 V, 1000 rpm PMBLDC MOTOR WITH DIFFERENT POLE ARC

Sr.No	Pole Arc (degree)	Peak to peak Cogging torque (N.m)
1	62	0..89
2	60	0.49
3	58	0.34
4	56	0.74
5	54	1.09

Fig.4 shows the field plot for 58 rotor pole arc (degree). It is observed that the flux density in different sections of the magnetic circuit is as per the assumptions.

[B] Cogging Torque Analysis for 746 W, 230 V, 2000 rpm PMBLDC Motor

Fig.5 shows the FEA modal for 746 W, 230 V, 2000 rpm

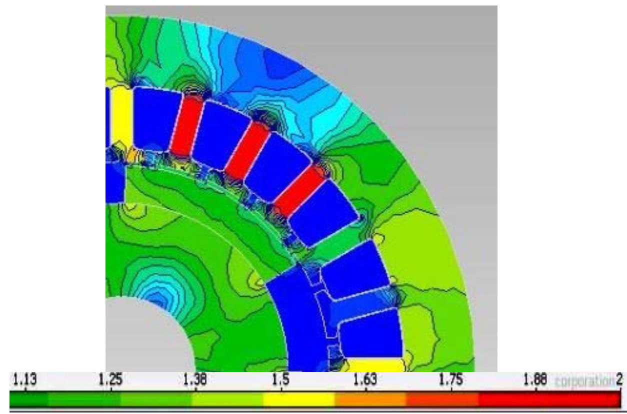

Figure 4 Field plot of 200 W PM BLDC for 58 pole arc

radial flux PMBLDC motor with magnet pole arc of 56 degree. The magnet pole arc is varied from 62 to 54 degree and cogging torque profile is obtained. The cogging torque for the same motor is shown in Fig 6. Peak to peak cogging torque is influenced by variation of magnet pole arc. Minimum peak to peak cogging torque is observed when magnet pole arc is 56 degree. From the results shown in table, it is concluded that by reducing magnet pole arc from 62 degree to 56 degree, reduction in cogging torque is from 2.16 Nm to 0.62 Nm, which is 71.3 % reduction from original design. Further reduction in magnet pole arc is not advisable, as it will again increase the cogging torque. Magnet pole arc with 56 degree will give the best results in terms of cogging torque.

Fig.7 shows the field plot for 56 rotor pole arc (degree). It is observed that the flux density in different sections of the magnetic circuit is as per the assumptions.

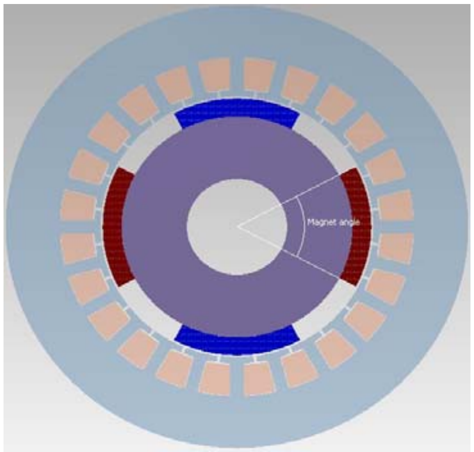

Figure 5. Pole arc 56 (degree)

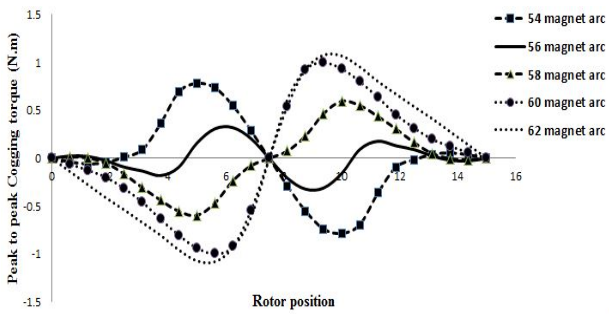

Figure 6 Cogging torque profile of 746 W PMBLDC Motor

Table 2
PEAK COGGING TORQUE FOR 746 W, 230 V, 2000 rpm PMBLDC MOTOR WITH DIFFERENT POLE ARC

Sr.No	Pole Arc (degree)	Peak to peak Cogging torque (N.m)
1	62	2.16
2	60	2.00
3	58	1.20
4	56	0.62
5	54	1.56

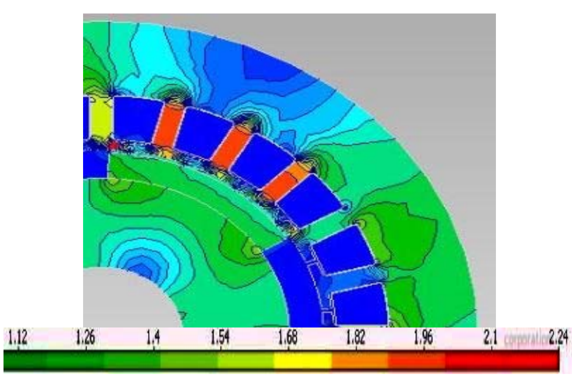

Figure 7. Field plot of 746 W PMBLDC for 56 pole arc

[C] Cogging Torque Analysis for 2.2 kW, 230 V, 1450 rpm PMBLDC Motor

Fig.8 shows the FEA modal for *2.2 kW*, *230* V, *14*50 rpm PMBLDC Motor with magnet pole arc 60 degree. Cogging torque profile for same motor is shown in Fig 9 with different magnet pole arcs. Table 6 shows the values of peak to peak cogging torque with different pole arc. From the results shown in table, it is concluded that by reducing magnet pole arc from 62 degree to 60 degree, reduction in cogging torque is from 5.74 Nm to 2.2 Nm, which is 61.67 % reduction from original design. Further reduction in magnet pole arc is not advisable, as it will again increase the cogging torque. Magnet pole arc with 60 degree will give the best results in terms of cogging torque.

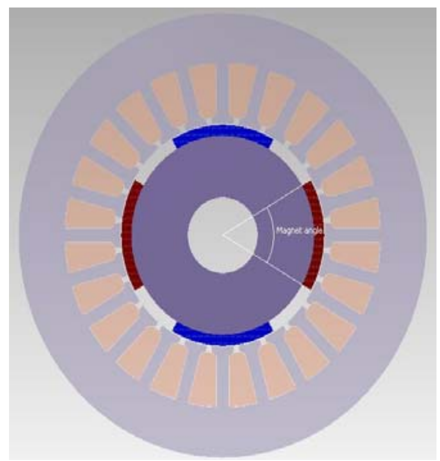

Figure 8. Pole arc 60 (degree)

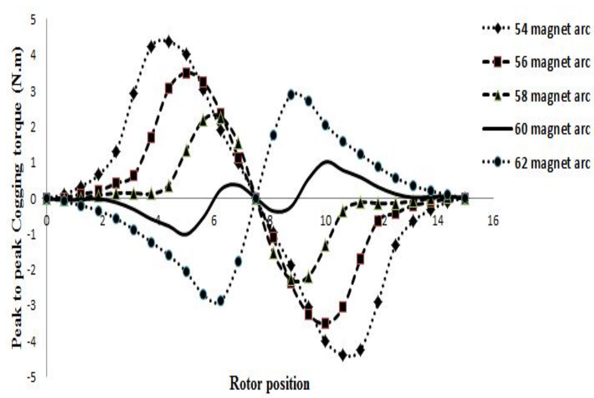

Figure 9 Cogging torque profile of 2.2 kW PMBLDC Motor

Table 3
PEAK COGGING TORQUE FOR 2.2kW, 230 V, 1450 rpm PMBLDC MOTOR WITH DIFFERENT POLE ARC

Sr.No	Pole Arc (degree)	Peak to peak Cogging torque (N.m)
1	62	5.74
2	60	2.20
3	58	4.40
4	56	7.00
5	54	8.87

Fig.10 shows the field plot for 60 rotor pole arc (degree). It is observed that the flux density in different sections of the magnetic circuit is as per the assumptions.

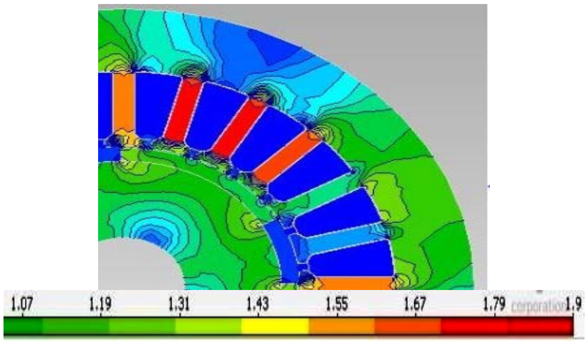

Figure 10 Field plot of 2.2 kW PM BLDC for 58 pole arc

IV. CONCLUSION

In this paper, influence of magnet pole arc on the cogging torque of three standard rating Radial Flux Permanent Magnet Brushless DC Motors is investigated. Minimum peak to peak cogging torque is obtained at rotor pole arc 58 degree, 56 degree and 60 degree for 200 W, 746 W and 2.2 kw motor respectively. Based on design variations and subsequent analysis, designer has to select pole arc for minimum cogging torque. The result confirms that magnet pole arc variation approach can significantly reduce the cogging torque and helps to improve the torque quality of PMBLDC motors.

REFERENCES

[1] D. C. Hanselman, "Brushless Permanent Magnet Motor Design" New York McGrow-Hill 1994

[2] J. R. Handershoot Jr. and T. J. E. Miller, "Design of Brushless Permanent Magnet Motors. Oxford, U.K.: Oxford, 1994

[3] Amit N Patel, Malay A Bhavsar, Parth N Patel "Sizing of Radial Flux Permanent Magnet Brushless DC Motor", International Conference on Advances in Engineering and Technology (ICAET-2013), Lovavala, during 15-17 May 2013

[4] Amit N Patel, Kishan Patel, Tushar Chauhan,"Influence of Different types of Stator Slots on Torque Pfofile of Surface Mounted PM Motor, International Journal of Computer Applicationin in Engineering Science, June 2014

[5] Luke Dosiek, Student Member IEEE, Pragasen Pillay, Fellow IEEE, "Cogging Torque Reduction in Permanent Magnet Machines", IEEE Transactions On Industry Applications, VOL. 43, NO. 6, November/December 2007

[6] Metin Ayden, Member IEEE, Mehmet Gulec, Student Member Member IEEE, "Reduction of Cogging Torque in Double-Rotor Axial-Flux Permanent-Magnet Disc Motors: A Review of Cost- Effective Magnet-Skewing Techniques With Experimental Verification, IEEE Transactions On Industrial Electronics, VOL. 61, NO. 9, September 2014