Cogging Torque Minimization by Magnet Edge Inset Variation Technique in Radial Flux Surface Mounted Permanent Magnet Brushless DC (PMBLDC) Motor

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***Abstract*-This paper presents technique to minimize cogging torque in radial flux surface mounted Permanent Magnet Brushless DC (PMBLDC) motor. Variation in magnet edge inset is done and its influence on cogging torque is analyzed. Magnet edge inset is varied from 0 mm to 2 mm keeping other dimensions same in three standard rating radial flux surface mounted Permanent Magnet Brushless DC Motors. It is observed that this technique is effective and cogging torque can be considerably reduced whereas average torque is marginally affected. Hence, it is very essential to select proper magnet edge inset to reduce the cogging torque in order to improve the performance.**

Index Terms- Cogging Torque, Permanent Magnet Brushless DC (PMBLDC) Motor, Permanent Magnet, Finite Element Analysis (FEA)

I. INTRODUCTION

Permanent Magnet Brushless DC motors are widely used in industrial as well as domestic applications due to their distinct advantages like high efficiency, wide speed range, high torque to current ratio, high power density, fast dynamic response, compact size, noiseless and sparkles operation and high torque to inertia ratio[3][4]. Major limitation of PMBLDC motor is high cogging torque. One of the paramount problem in design of the PM electrical machines is to reduce the cogging torque which affects the machine performance and results in shaft vibration, acoustic noise and damage to drive component. Cogging torque deteriorates performance of PMBLDC motor. In order to enhance performance it is very essential to minimize cogging torque. A large number of PMBLDC motor applications such as aerospace, defense, marine, medical etc. require minimum cogging torque. For such applications, torque quality becomes exceptionally significant and motor design and analysis must be finalized paying attention to cogging torque. There are different approaches to reduce the cogging torque from either machine design or control perspectives. The machine design techniques to minimize the cogging torque is by optimization of the electrical machine's structural Parameters. Control techniques require the erudite current excitations and are highly dependent on response and accuracy of the used sensors. There are various design techniques on stator side and rotor side to minimize cogging torque. Selection of any specific technique is important as it can affect production cost and complexity manufacturing process. One of the technique to reduce cogging torque is variation in magnet edge inset. Magnet edge inset is the inset of the ends of magnet from sleeve in millimeters. Computer Aided Design (CAD) and Finite Element Analysis (FEA) of radial flux PMBLDC motor is carried out for three standard ratings: (i) 70 W, 24 V, 350 rpm (ii) 2.2 kW, 230 V, 1450 rpm and (iii) 20 kW, 230 V, 1500 rpm. FEA is carried out to analyze the effect of permanent magnet edge inset variation on cogging torque. Cogging torque can be significantly reduced by proper selection of magnet edge inset as it has greater impact on reducing peak to peak cogging torque.

II. DESIGN OF RADIAL FLUX PMBLDC MOTOR

Design of radial flux Permanent Magnet Brushless DC motor is intensive due to 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

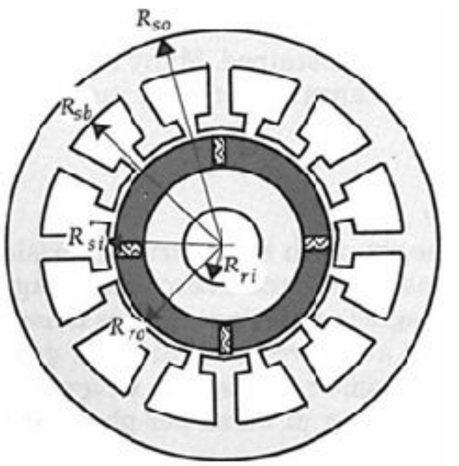

Fig. 1 Main dimensions of Radial Flux (PMBLDC) Motor

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Axial length (L), Rotor outer diameter (D_{ro}) and Stator outer diameter (D_{so}) are the main dimensions of the radial flux PMBLDC motor. These main dimensions are calculated based on assumption of various design variables like average flux density, slot loading, winding factor, slot packing factor etc. [6].

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 and type of rotor i.e. interior rotor or exterior rotor [2]. It is very essential to select proper number of rotor poles to achieve good quality of torque profile.Range of length of air gap is usually 0.5mm 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 in different sections of magnetic circuit of motor. If performance objectives are not met, adequate modifications have to be made in design.

III. THE EFFECT OF MAGNET EDGE INSET VARIATION ON COGGING TORQUE

Cogging torque is generated due to interaction between the rotor permanent magnets and the stator tooth. It is caused by an uneven air-gap reluctance due to slotting of stator core. It is independent of current excitation. It is a magneto static effect. Cogging torque can be reduced by proper selection of Magnet Edge Inset as peak to peak value and shape of the cogging profile depends on magnet edge inset colossally and on the physical geometry of the magnet. In its most fundamental form, cogging torque can be expressed by,

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

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 either reducing ϕ_g or $\frac{dR}{d\theta}$. Air-gap flux should not be reduced hence variation in air-gap reluctance should be reduced. Cogging torque can be represent as a Fourier series [5].

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

Where,

$\text{n} = \text{LCM}(N_s, N_p)$

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 70 W, 24 V, 350 rpm Radial Flux PMBLDC Motor

Fig.2 shows the FE model of 70 W, 24 V, 350 rpm radial flux PMBLDC motor with magnet edge inset 1.5 mm. The magnet edge inset is varied from 0 to 2.0 mm and cogging torque profile is obtained. The cogging torque profile for the same motor is shown in Fig 3. Peak to peak cogging torque is influenced by the variation in magnet edge inset. Minimum peak to peak cogging torque is obtained when magnet edge inset is 1.5 mm. From the results shown in fig.4, it is inferred that by increasing magnet edge inset from 0 to 2.0 mm, reduction in peak to peak cogging torque is achieved, which is 86.23% reduction from original design. Further increment in magnet edge inset is not advisable, as it will decrease the average motoring torque. Magnet edge inset of 1.5 mm gives the best results in terms of cogging torque with marginal variation in average motoring torque.

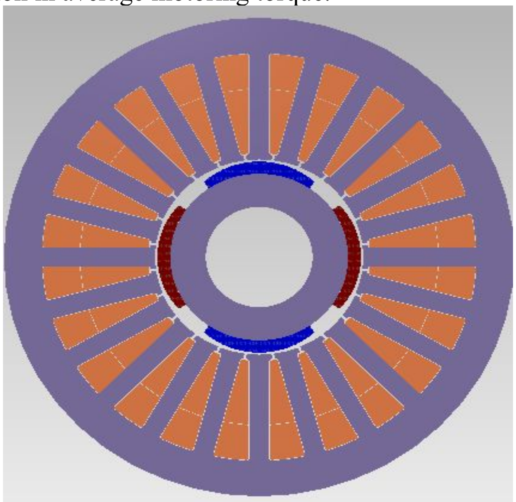

Fig.2 FE model of 70 W motor with magnet edge inset 1.5 mm

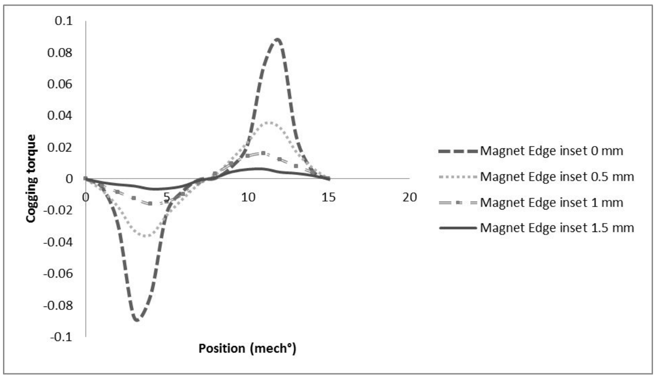

Fig. 3 Cogging torque profile of 70 W Motor

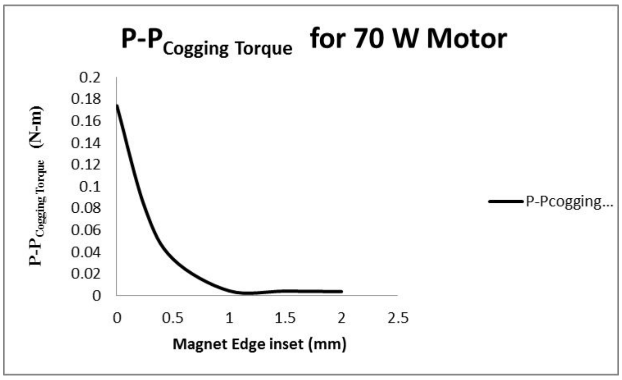

Fig.4 Cogging torque $_{vs}$ magnet edge inset of 70 W motor

FE analysis is carried out to check actual flux density in different sections of magnetic circuit. Fig.5 shows the flux density plot of quarter part of motor.

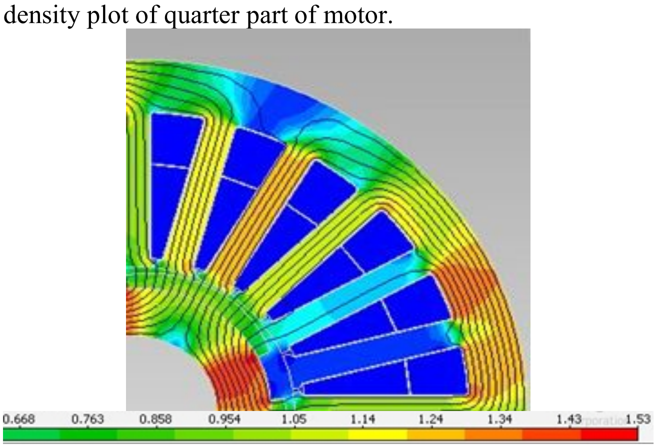

Fig. 5 Flux density plot of 70 W motor with magnet edge inset 1.5 mm

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

Fig.6 shows the model for 2.2 kW, 230 V, 1450 rpm radial flux PMBLDC motor with magnet edge inset of 1.5 mm. The magnet edge inset is varied from 0 to 2.0 mm and cogging torque profile is obtained. The cogging torque profile for the same motor is shown in Fig 7. Minimum peak to peak cogging torque is obtained with 1.5 mm magnet edge inset. From the results shown in fig.8, it is inferred that by increasing magnet edge inset from 0 mm to 1.5 mm, reduction in peak to peak cogging torque is achieved, which is 87.5 % reduction from original design. Further increment in magnet edge inset is not advisable, as it will decrease the required torque. 1.5 mm magnet edge inset gives the best results in terms of cogging torque.

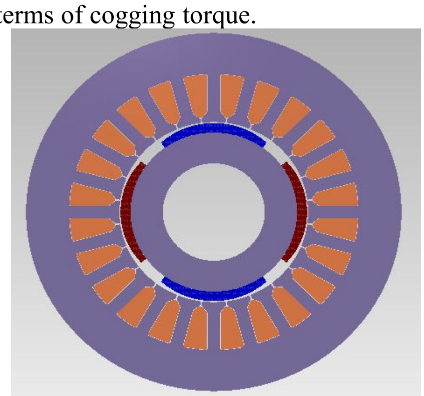

Fig. 6 FE model of 2.2 kW motor with magnet Edge Inset 1.5 mm

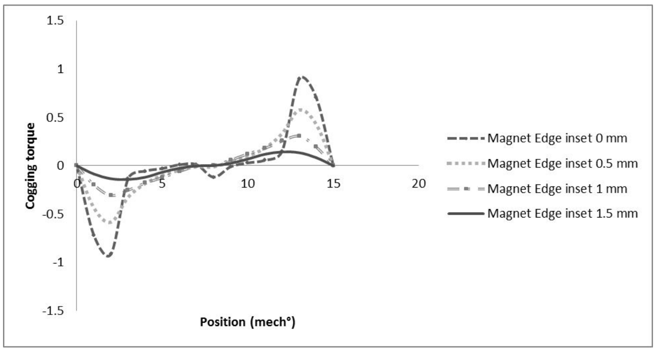

Fig. 7 Cogging torque profile of 2.2 kW Motor

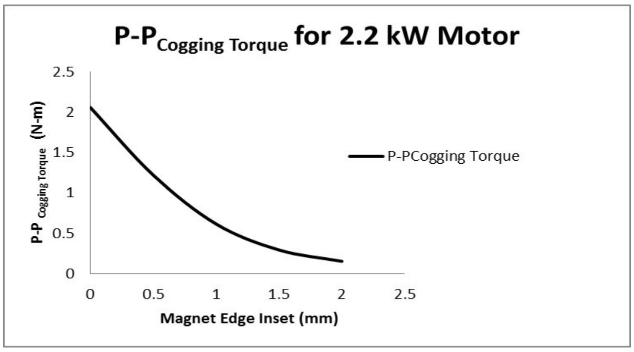

Fig. 8 Cogging torque $_{vs}$ magnet edge inset of 2.2 kW motor

FE analysis is carried out to check actual flux density in different sections of magnetic circuit. Fig.9 shows the flux density plot of quarter part of motor.

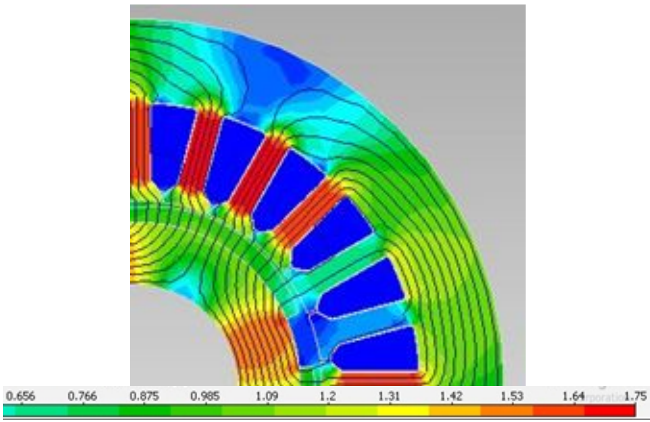

Fig. 9 Flux density plot of 2.2 kW motor with magnet edge inset 1.5 mm

[C] Cogging Torque Analysis for 20 kW, 230 V, 1500 rpm PMBLDC Motor

Fig.10 shows the FEA modal for 20 kW, 230 V, 1500 rpm PMBLDC Motor with magnet edge inset of 1.5 mm. Cogging torque profile for same motor is shown in Fig 11 with different magnet edge inset. From the result shown in Fig. 12, it is inferred that by increasing magnet edge inset from 0 mm to 1.5 mm, reduction in cogging torque is achieved, which is 75 % reduction from original design. Further increment in magnet edge inset is not advisable, as it will again decrease the desired torque. Magnet edge inset of 1.5 mm gives the best results in terms of cogging torque.

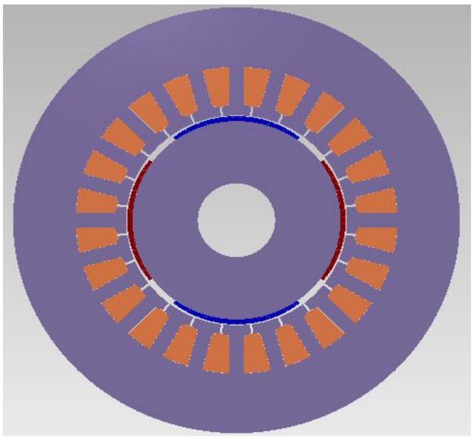

Fig.10 FE model of 20 kW motor with magnet edge Inset 1.5 mm

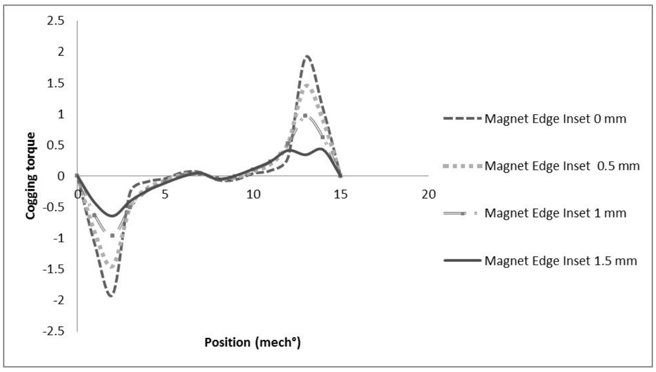

Fig. 11 Cogging torque profile of 20 kW Motor

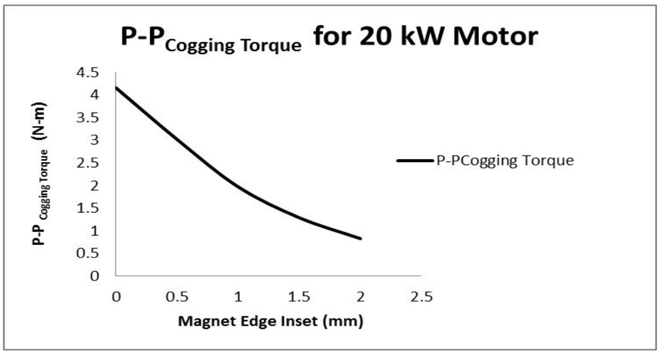

Fig.12 Cogging torque vs magnet edge inset of 20 kW motor

FE analysis is carried out to check actual flux density in different sections of magnetic circuit. Fig.13 shows the flux density plot of quarter part of motor.

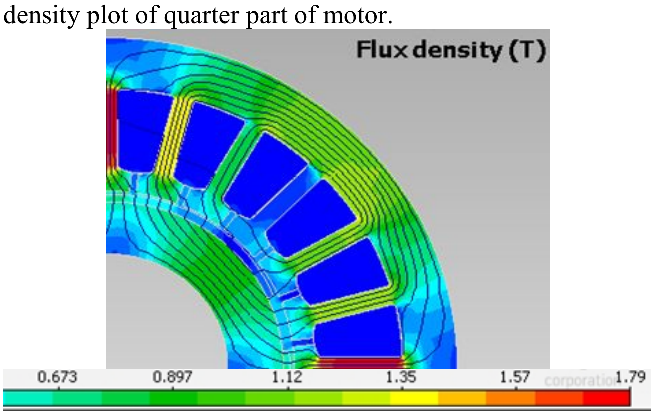

Fig. 13 Flux density plot of 20 kW motor with Magnet Edge Inset 1.5 mm

IV. CONCLUSION

Effect of magnet edge inset variation on the cogging torque of three standard rating radial flux surface mounted Permanent Magnet Brushless DC Motors is analyzed in this paper. Minimum peak to peak cogging torque is obtained at 1.5 mm magnet edge inset in 70 W, 2.2 kW and 20 kW motor respectively without affecting other performance parameters considerably. Based on design variations and subsequent analysis, designer has to select proper magnet edge inset with proper magnet pole arc for minimum cogging torque. The results confirm that magnet edge inset variation approach has significantly reduced the cogging torque hence it is an effective technique.

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