Influence of Different Types of Stator Slots on Torque Profile of Surface Mounted PM Motors

Amit N. Patel[1], Kishan Patel[2], Tushar Chauhan [2]

Institute of Technology, Nirma University, Ahmadabad, India.

[1]amit.patel@nirmauni.ac.in
[2]10bee005@nirmauni.ac.in
[2]10bee021@nirmauni.ac.in

***Abstract*— In this paper effort is made for the torque ripple minimization of 70 W, 24 Volt, 350 rpm, surface mounted radial permanent brushless DC (SPM BLDC) motor. The stator slot shaping is analyzed. The results obtained from FE analyses have been discussed. Design of stator slots have influence upon the cogging torque. Options available for slot designs viz, square type slots, square with curved tangs type slots, round type slots are taken into consideration in this paper. Uniformity of air gap for each type of slot varies so as the torque profile. Results obtained for 70 W, 24 Volt, 350 rpm motor are verified by 200 W, 24 Volt, 1000 rpm motor.**

***Keywords*— Finite Element Analysis (FEA), Permanent Magnet, Surface Mounted PM Motors, Computer Aided Design (CAD), Stator Slot Shaping**

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 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, which can result either run it at low temperature or to increase shaft power so that maximum allowable temperature has been 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.

Different types of stator slots are considered and analyzed using two dimensional (2-D) FEA.

II. Design Considerations & CAD Of SPMBLDC Motor

A. Air gap flux density pattern

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

B. 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 (BHmax) and retentivity (Br). The selection depends on the cost and performance requirement. Nd-Fe-B magnetic material is selected here.

C. Specific loadings

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

D. 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.

E. Length of air gap

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

F. Stator slot shape

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

Computer Aided Design (CAD) program is developed for surface mounted permanent magnet brushless dc motor. This CAD program consists four stages viz. [1] calculation of main dimensions [2] stator design [3] rotor design and [4] performance estimation.

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

III. Stator Slot Shaping

Torque ripple minimization is essential to enhance performance of PM motors. Compared to sinusoidal permanent magnet brushless DC motor the torque ripple is high in case of trapezoidal type permanent magnet brushless DC motor. For AC machines there is greater emphasis on smooth operation so that winding layout is more sinusoidal and less torque ripple. Mainly there are two sources of torque ripple namely [1] cogging torque due to interaction between slotted stator structure and magnetic field created by permanent magnet and [2] mutual torque ripple created by mismatch between exciting currents. Torque ripple ca n be minimized by reducing cogging torque and/or by reducing mutual torque ripple. The proper design of magnetic circuit of motor reduces cogging torque and proper excitation reduces mutual torque ripple.

In this paper the effect of improvement in magnetic circuit design on toque ripple is presented. Efforts are put to analyze motor using different type of stator slots with FEA. For reference, a model of 70 W, 24 Volt, 350 rpm is selected and for this model CAD programming is carried out. From CAD results FE model of the same rating is made and torque profile is analyzed. For this model FE analysis results are achieved as shown in table below:

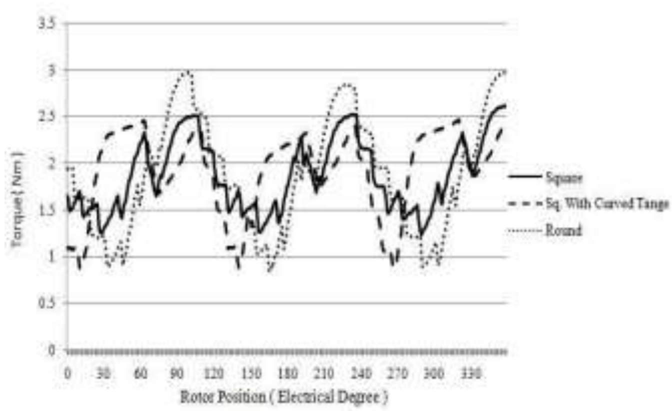
TABLE-I
PWM RESULTS FOR 70 W, 24 Volt, 350 rpm MODEL

Parameters	**FE analysis Results**
Torque (Nm)	1.91
Input Power (kW)	0.0852
Output Power (kW)	0.07
Efficiency (%)	82.2
Torque per unit volume (Nm/mm^2)	2.38E-05
Supply Current (A)	3.55

IV. Various Stator Slots

There are different types of stator slots which can be designed for PM motors i.e., square type slot, square with curved tangs type slot, round type slot, parallel type slot, etc. FE analysis for each type of slot is done and it is verified that square type slot gives least ripple.

Figure shows variation of torque for 70 W, 24 Volt, 350 rpm motor with respect to rotor angle for 3 selected



options of slot designs:

Fig 1: Torque profile comparison for different types of slot designs for 70 W, 24 Volt, 350 rpm Motor

Torque ripple can be found out by formula shown below:

$$\%ripple = \frac{T_{max} - T_{min}}{T_{avg}} * 100$$

Results of FE analysis for 70 W, 24 Volt, 350 rpm motor is validated by applying the same method for 200 W, 24 Volt, 1000 rpm motor. Figure shows the variation in torque for 200 W, 24 Volt, 1000 rpm motor with respect to rotor angle for 3 selected options of slot designs:

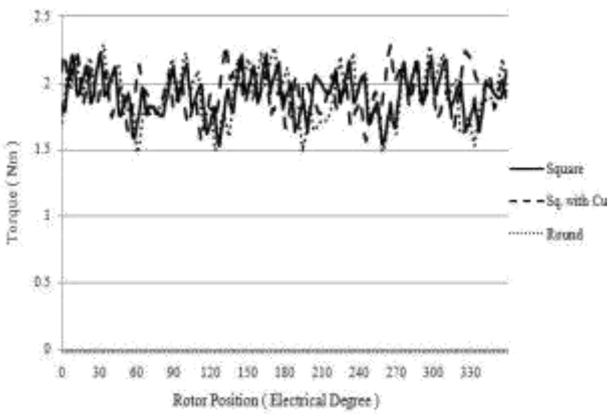


Fig 2: Torque profile comparison for different types of slot designs for 200 W, 24 Volt, 1000 rpm Motor

It can be seen from figure above that an observation seen from 70 W, 24 Volt, 350 rpm motor also remains true for 200 W, 24 Volt, 350 rpm motor that square type of slot contributes to least ripple.

V. CONCLUSION

Using the proper shaping of stator slots, the torque ripple of surface permanent brushless DC (SPM BLDC) motor is reduced. In each type of stator slot design average torque remains almost constant while difference between torque dip varies. FE analysis is carried out for different types of slots for two differently rated motors (i) 70 W, 24 V, 350 rpm (ii) 200 W, 24 V, 1000 rpm. After FE analysis of each type of stator slot it is inferred that square type of slot gives better performance for SPM BLDC motor.

REFERENCES

[1] Parag Upadhyay and K. R. Rajagopal, "Torque Ripple Minimization of Interior Permanent Brushless DC Motor Using Rotor Pole Shaping"

[2] "Sizing of Radial Flux Permanent Magnet Brushless DC Motor" International Conference on Advances in Engineering and Technology (ICAET-2013) organized by SPJ Center for Multidisciplinary Research(SCMR) & SKN Sinhgad Institute of Technology and Science, Lonavala, Pune,during 15-17 May 2013

[3] J. R. Hendershot and T. J. E Miller, Design of Permanent-MagnetMotors. Oxford, U.K.:Clarendon, 1994.

[4] D. C. Hanselman, Brushless Permanent Magnet Motor Design. Lebanon, OH: Magna Physics, 2006.

[5] Parag Upadhyay and K. R. Rajagopal, "FE Analysis and CAD Radial-Flux Surface Mounted Permanent Magnet Brushless DC Motors" IEEE Transactions On Magnetics, Vol. 41, No. 10, October 2005

[6] Bhim Singh and Devendra Goyal, "Computer Aided Design of Permenent Magnet Brushless DC Motor for Hybrid Electric Vehicle Application", 2006.