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Analysis of V – Shaped Interior Permanent Magnet Synchronous Motor for Low Torque Ripple

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ABSTRACT-- Reduction of torque ripple plays a vital work in the design of motors, especially in permanent magnet motors. This paper shows a study on the design of V shaped interior permanent magnet synchronous motor with low torque ripple. Arrangements of permanent magnets in the motor also cause a major effect in the torque ripple of the motor. MagNet Software, Finite Element Analysis has been used for the better design considering permanent magnet arrangement. The better magnet arrangement for IPMSM is presented after comparing the results.

KEYWORDS— IPMSM, torque ripple, V shaped PMSM.

I. INTRODUCTION

Permanent magnet synchronous motors are been used in the Hybrid electric vehicles recently for their high efficiency and high reliability. Permanent magnet synchronous motor with interior magnets have high power density per motor volume, little volume, light weight and high power factor; these advantages make the Interior-PMSMs especially suitable for HEV applications. The interior permanent magnet synchronous motor can generate both magnetic torque and reluctance torque. High cogging torque and torque ripple has been generated because of this reluctance torque. Torque ripple causes noise and vibration. These noise and vibration creates a major problem in the designing of interior permanent magnet synchronous motor. In interior Permanent Magnet Synchronous Motor the torque ripple is majorly depends on the permanent magnet placement inside the rotor. Permanent magnet placement is to be optimised to improve overall performance of interior permanent magnet synchronous motor.

In interior Permanent magnet synchronous motor there are lot of rotor configurations are available in markets. In this paper we have discussed with the V – shaped interior permanent magnet synchronous motor. In this configuration, two permanent magnets per pole arc placed in a certain angle taking the form of a "V". In this paper, permanent magnet placements in Interior permanent magnet synchronous motor have been discussed.

II. ANALYSIS MODEL

In this paper, we have investigated the 4 pole 24 slot Interior permanent magnet synchronous motor for permanent magnet placement has been discussed. The specifications of analysis model have been given in the table 1.

TABLE 1
SPECIFICATIONS OF ANALYSIS MODEL

Power (kW)	1.5
Input voltage (V)	415
Base speed (deg/s)	9000

A. Stator Model

Stator model have been chosen with the power and supply voltage. In this model 24 slots has been designed with tapered slot shape. Single layer wave winding has been used in this. Figure 1 shows the stator model. Stator Parameters values are given in table 2.

B. Rotor Model

Rotor configuration plays a major role in the reduction of torque ripple. V shaped buried permanent magnets has been shown in the rotor model of figure 2. Rotor parameters are given in the table 3.

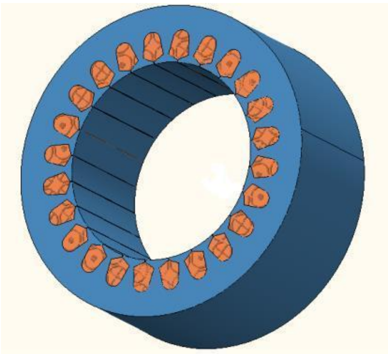


Fig. 1 Stator of IPM

TABLE 2
PARAMETERS OF THE STATOR

Stator length *mm*	80
Stator inner Radius *mm*	44.5
Stator outer radius *mm*	70
Air gap *mm*	1
Shoe tip thickness mm	2
Shoe root thickness mm	7
Stator yoke width mm	22
Slot opening mm	0.4
Turns	45

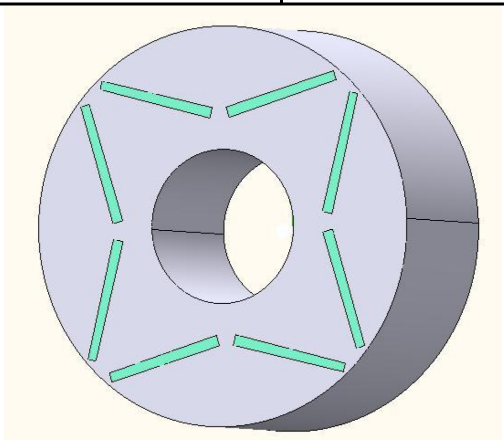


Fig. 2 IPM rotor

TABLE 3
ROTOR PARAMETER

Rotor Inner radius *mm*	25
Rotor outer radius *mm*	44
Magnet thickness *mm*	5
Magnet to yoke depth *mm*	13.3
Pole arc	60

III. PULSATING TORQUES

IPM motors used in HEV's in which a smoothness of the torque is of essential importance. It is then evident that pulsating torques creating vibrations and acoustic noise in the motor are to be minimized, which means that the pulsating torques should be less than 1 to 2 % of the rated torque. Pulsating torque consists of two major components 1) torque ripple and 2) cogging torque. The reasonable method in eliminating pulsating torques may be obtained in improving the motor design.

IV DESIGN VARIABLES

Pulsating Torques can be minimized by the permanent magnet placement in the rotor. In this paper, for altering the permanent magnet arrangement we have taken two design variables. 1) Distance from shaft to the magnets (D) and 2) thickness of the magnets (T). These design variables are shown in figure 4.

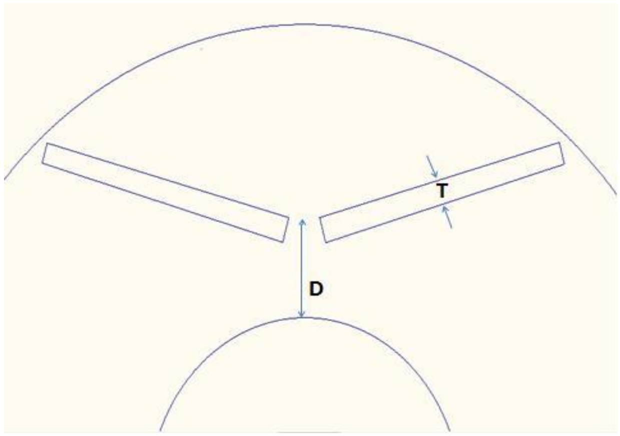


Fig. 4 Design variables

A. Design area

For optimal permanent magnet placement in IPM motors we can't go for all the possible design parameters at a single design. So we have to establish a design conditions for each design parameters. Each design parameters have a minimum and maximum value. For these values we will get four combinations. Table 4 presents the four combinations in this paper.

TABLE 4
PERMANENT MAGNET PLACEMENT COMBINATIONS

Combination	Distance (D)	Thickness(T)
1	13.3	5
2	13.3	1
3	17.6	5
4	17.6	1

B. Finite Element Analysis

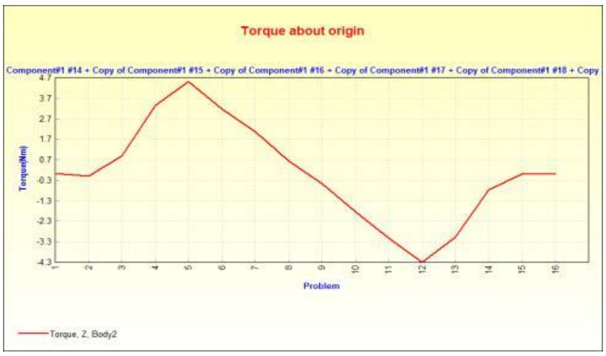
Actual motor fabrication of each combination takes several hours, heavy work and it is costly. Hence virtual motors are designed in MagNet software. FEA gives the performance characteristics of each combination.

V. ANALYSIS OF RESULTS

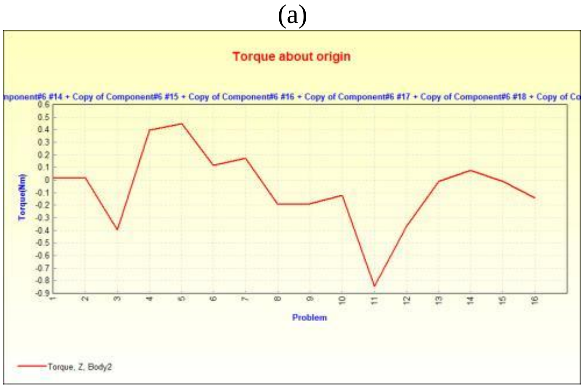
Four combinations have been simulated. Figure 5 shows the cogging torques of each combination. Table 5 gives the values of cogging torque. From the table 5 we can easily understand that cogging torque can be easily minimized by decreasing the thickness (T) of the permanent magnet placed. And also the distance from yoke to permanent magnet (D) should be maximized. Figure 5 shows the torque ripples of each combination at base speed 9000 deg/s. Table 6 gives the values of torque ripple. From the table 6 it is obvious that torque can be minimised when there is minimum thickness (T) and minimum distance (D). Combination 4 has the minimum cogging torque and minimum Torque ripple. Speed and torque characteristics of this combinations has been given in figure 7.

TABLE 5
COGGING TORQUE

Combination	Cogging Torque (Nm)
1	9.2
2	1.55
3	6.7
4	1.52

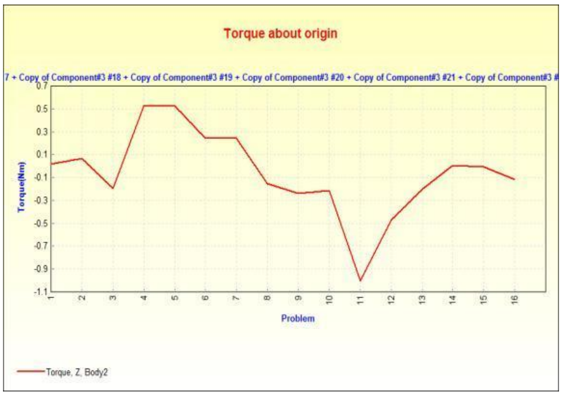


(a)



(b)

(C)



(d)

FIG. 5 COGGING TORQUES OF (a) COMBINATION 1, (b) COMBINATION 2, (c) COMBINATION 3, (d) COMBINATION 4

TABLE 6.
TORQUE RIPPLES

Combination	Torque ripple @ 9000deg/s (%)
1	8
2	2.4
3	17
4	4.4

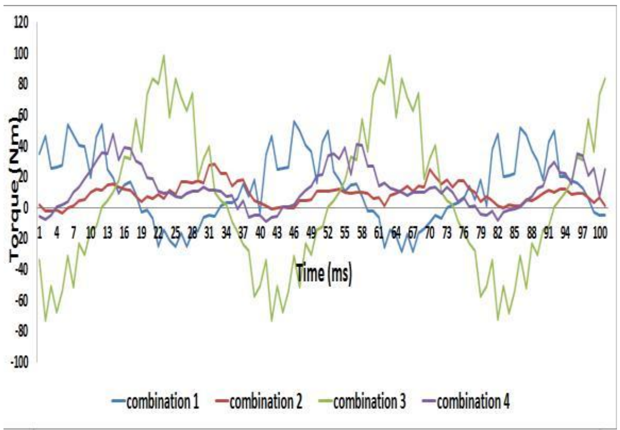
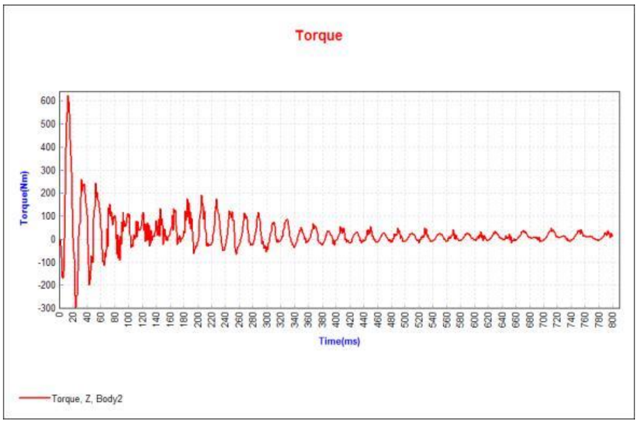


FIG. 6 TORQUE RIPPLE OF EACH COMBINATION

(a)



(b)

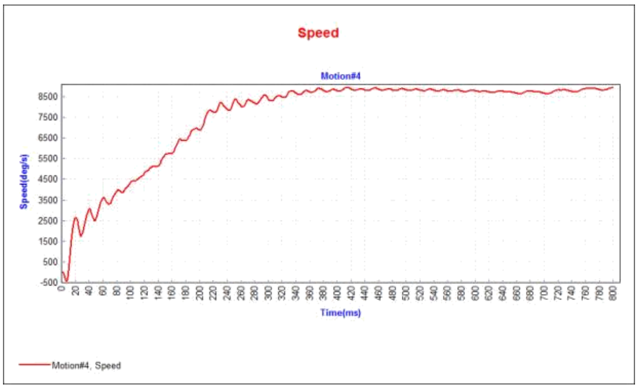


FIG. 7 (a) TORQUE, (b) SPEED CHARACTERISTICS OF IPMSM OF COMBINATION 4

VI .CONCLUSION

Placement of permanent magnets has been optimised using the design variables. IPM motor with better permanent magnet placement has been simulated and results are shown. The torque performance of proposed motor has low torque and cogging torque.

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