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Static Analysis of 18-Slot/16-Pole Permanent Magnet Synchronous Motor Using FEA

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ABSTRACT

This paper presents the static analysis of 18-slot/16-pole Permanent Magnet Synchronous Motor (PMSM) using Finite Element Analysis. The motor is designed from half model of rotor and stator. Then it is built until becoming a complete motor. The stator and rotor core are made from silicon steel laminations, and Neodymium magnets is used for permanent magnet and located at the rotor surface. A 120 turns of coil per phase is wounded around the 18-slot of the motor. It consists of winding for phase A, B, and C respectively. The phase windings are not supplied and the rotor is moved manually. Then the motor flux linkage, induced back-electromagnetic force, and cogging torque are simulated and results show the output performing correctly with the mathematical method. The developed motor can be improved by adjusting the stator tooth width.

Keywords: *Static Analysis, Permanent Magnet Synchronous Motor, Opera2D*

INTRODUCTION

Permanent Magnet Synchronous Motor (PMSM) is suitable to be applied in the electric vehicle as the main propulsion component. The research on PMSM still on-going and many researchers focusing on the optimization of the PMSM design. The slot/pole configuration of the PMSM will affect the cogging torque [1]. The different slot winding of PMSM will also affect the cogging torque and radial force [2]. It seems that some modification on the motor dimensions can reduce the cogging torque, and resulting in improved performance of the developed motor. In this paper, different value of stator tooth widths is done and compared to evaluate the effect of magnetic flux density in the stator tooth.

Literature Review

The dimension of the developed motor is determined by selecting fixed parameter such as stator outer radius, motor axial length, magnet thickness, and airgap length. Other parameters are calculated such as optimal split ratio, stator bore radius, stator yoke radius, tooth tang height, tooth body width, and rotor inner radius. Some related issues on designing windings in AC motors should be considered such as slot pitch angle, pole pitch angle, coil span, coils per pole, slot/pole/phase, slot/pole, single layer or double layer windings, winding factor K_{wn}, distribution factor K_{dn}, and pitch factor K_{pn}. These factors are used to determine the rms phase emf with algebraic sum of rms coil emfs. There are two types of windings configuration for 3-phase motors i.e. integral slot motor and fractional slot motor. The coil selections for phase windings in fractional slot motor are based on the coil mmf vectors. The air gap flux density B_g can be estimated using Equation 1 [3, 4],

$$B_g = \frac{B_r}{1 + \frac{\mu_r l_g}{h_m}} \tag{1}$$

where μ_r is magnet permeability, B_r is magnet remanence, l_g is airgap length, and h_m is magnet thickness. The stator bore radius is obtained from the optimal split ratio. The tooth body width W_{tb} is calculated using Equation 2 [3, 4],

$$W_{tb} = \frac{\phi_{sp}}{B_{sat} l_a} \tag{2}$$

where ϕ_{sp} is total flux per stator tooth, B_{sat} is maximum flux density in steel iron, and l_a is motor axial length. The stator yoke radius R_{sy} is calculated using Equation 3 [3, 4],

$$R_{sy} = R_{so} - \frac{\phi_{sp}}{2B_{sat} l_a} \tag{3}$$

where R_{so} is stator outer radius. The tooth tang height W_{tt} is calculated using Equation 4 [3, 4],

$$W_{tt} = \frac{\phi_x}{B_{sat} l_a} \tag{4}$$

where ϕ_x is the portion of flux entering the stator tooth pole. In general, the flux linkage of a coil is equal to the surface integral of the normal component of the magnetic flux density integrated over any surface spanned by that coil [5]. As the rotor rotates, the flux-linkages of the stator winding change with time. Under the assumption of a sinusoidal flux distribution and constant rotor speed, the resulting coil voltage will be sinusoidal in time [5]. Cogging torque describes the desire of the permanent magnets on the rotor to align with a maximum amount of ferromagnetic material [6, 7]. In addition to undesirable tangential force, *i.e.*, cogging torque, a motor may experience an undesirable radial force between the rotor and stator that varies as the rotor rotates [6, 7].

METHODOLOGY

The 18-slot/16-pole configuration is selected in the design because it has very high winding factor [3]. This winding factor will determine the motor performance. Figure 1 shows the half model of the 18-slot/16-pole PMSM. The motor dimensions are shown in the Table 1.

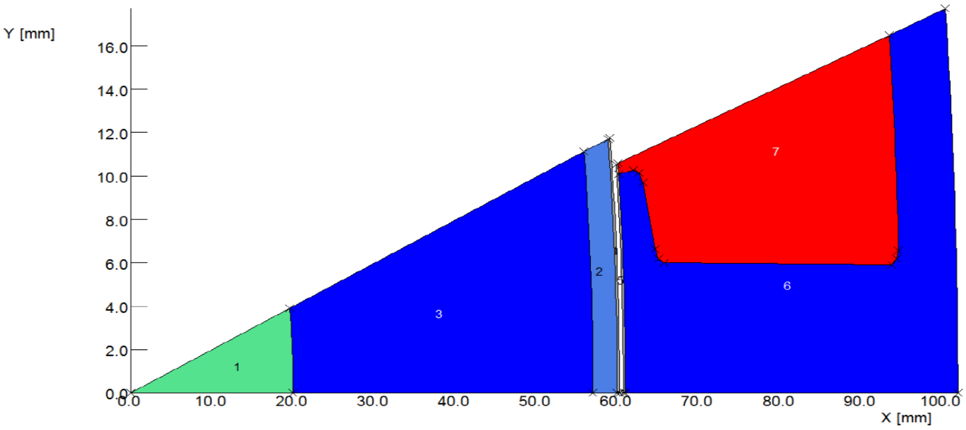

Figure 1: Half pole model of 18-slot/16-pole PMSM

After the half model is created, then the complete model of motor is developed followed by procedure explained in tutorial manual [3]. The developed motor has 16 poles and the program is written with data shown in the Table 2.

Table 1: Motor Dimension

Selected Parameters	Values	Calculated Parameters	Values
Stator Outer Radius, R_{so}	102 mm	Stator Yoke Radius, R_{sy}	95 mm
Motor Axial Length, l_a	100 mm	Tooth Tang Height, W_{tt}	4 mm
Magnet Thickness, h_m	3 mm	Tooth Body Width, W_{tb}	9.8 mm
Air gap Length, l_g	1 mm	Rotor Inner Radius, R_{ri}	20 mm
		Stator Bore Radius, R_{si}	61 mm

Table 2: Motor Simulation Data

Parameters	Values
End position of rotation	45 mech. deg.
Stepwidth for rotation	2 mech. deg.
Motor speed	750 rpm
Motor axial length	100 mm
Number of turns for coils/phase	120 turns

RESULTS AND DISCUSSION

The complete model of 18-slot/16-pole PMSM with 12 mm W_{tb} is shown in Figure 2. Eight pairs of south-north permanent magnet poles are mounted at the surface of the rotor.

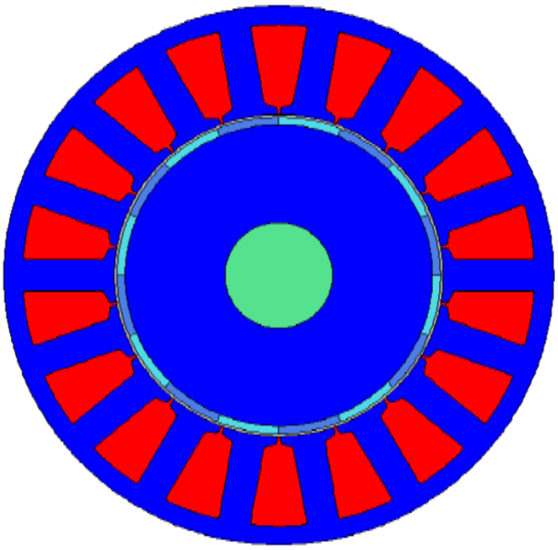

Figure 2: Complete model of 18-slot/16-pole PMSM with 12 mm W_{tb}

The flux linkage for phase A is measured and shown in Figure 3. It has 1.8 Wb-turns peak value of flux linkage. The motor has 71 V peak value of induced back-emf as shown in Figure 4 and this value may increase if analyze with another two phases of coils. The motor has low cogging torque as shown in Figure 5. The radial force acting between rotor and stator is shown in Figure 6.

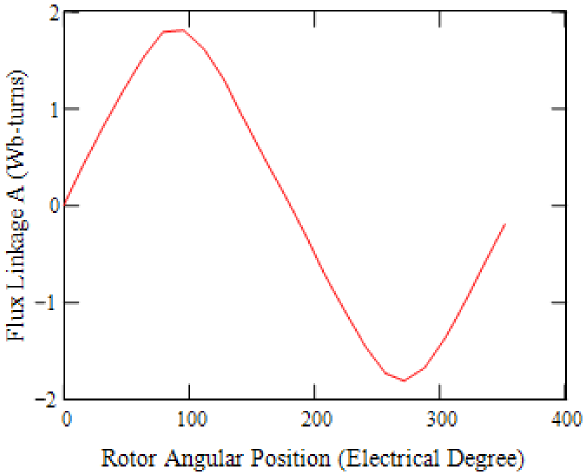

Figure 3: Flux linkage for phase A

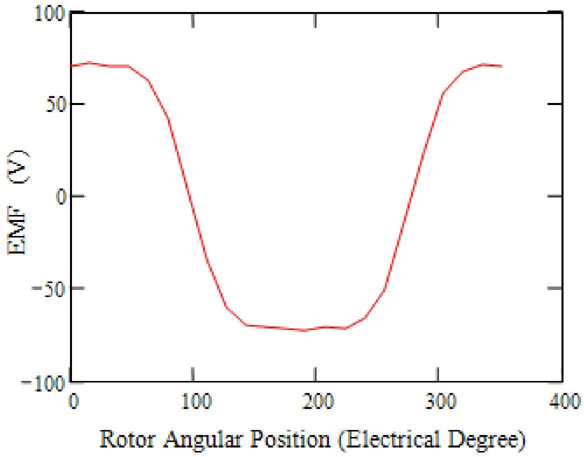

Figure 4: Induced back-emf for phase A

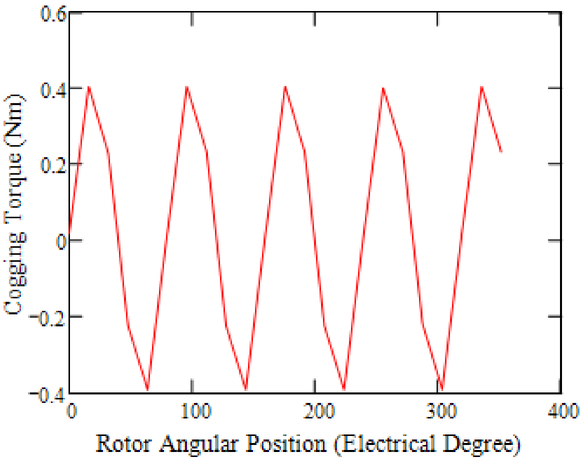

Figure 5: Cogging torque for phase A

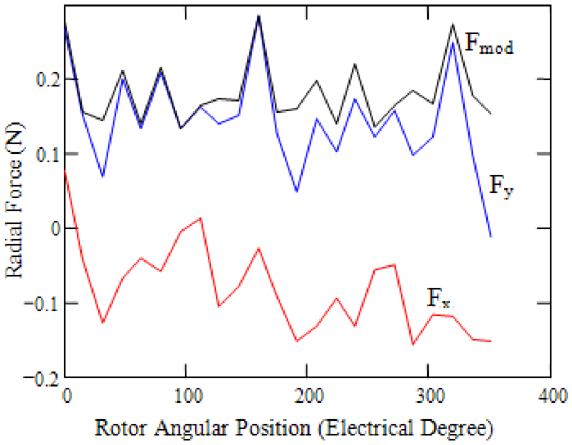

Figure 6: Radial Force for phase A

The magnetic flux density for 12 mm W_{tb} and 9.8 mm W_{tb} is shown in Figure 7 and 8 respectively. It shows that motor with 9.8 mm W_{tb} have highest magnetic flux density at it stator tooth.

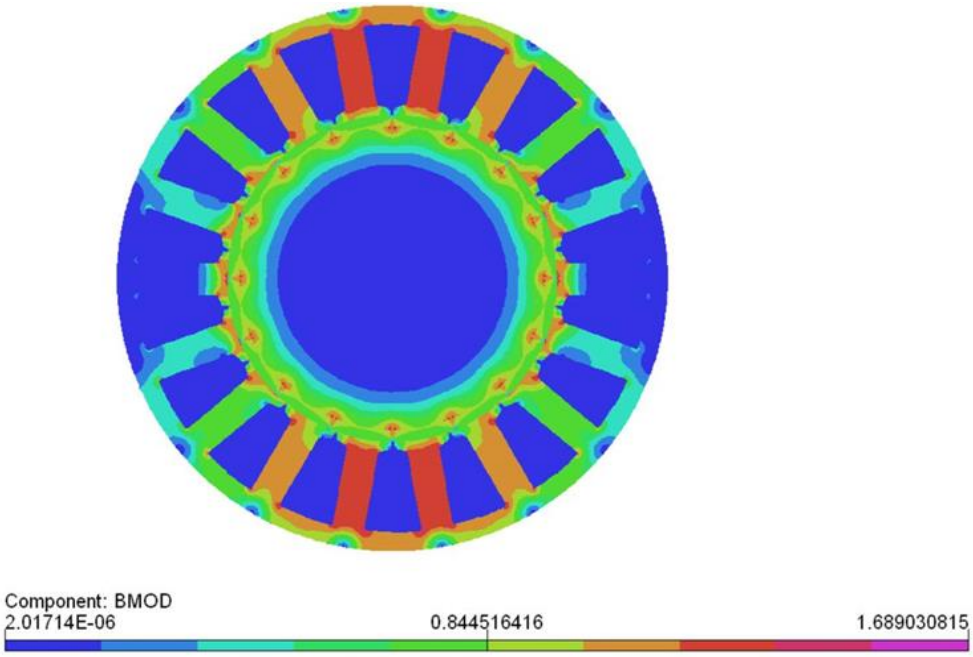

Figure 7: Magnetic flux density for 12 mm W_{tb}

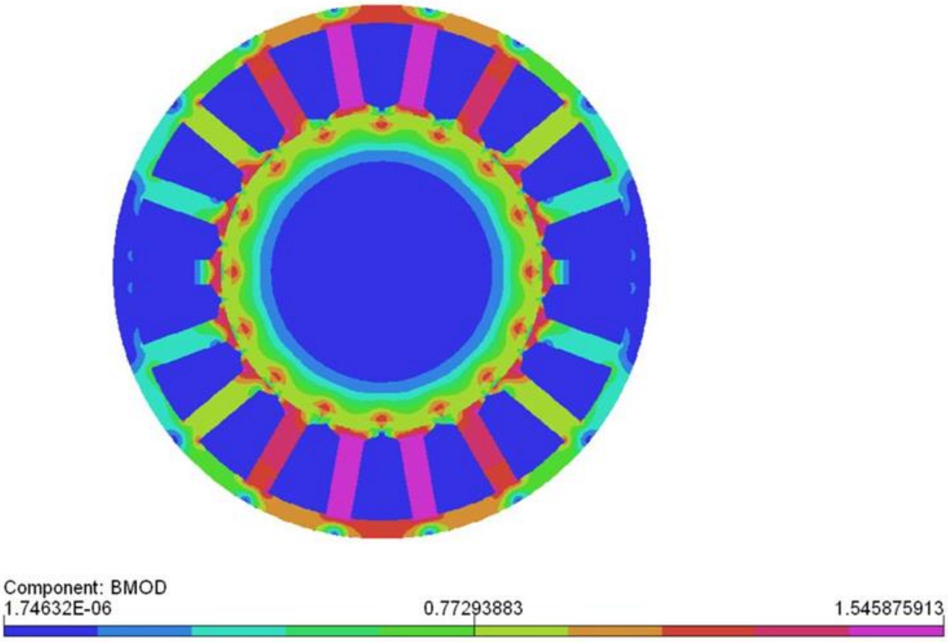

Figure 8: Magnetic flux density for 9.8 mm W_{tb}

The tooth width needs to re-adjust to have 80 % from the hysterisis curve of the steel iron. This can reduce the material size used to develop the stator. More number of coils can be fitted inside the slots. It shortens the magnetic flux pathway and allows the maximum magnetic properties of stator core during the motor operation without permanently magnetized it.

CONCLUSION

The magnetic flux density of the motor at stator tooth can be improved by re-adjusting stator tooth width so that the magnetic flux density of the stator tooth will be at least 80 % from the hysterisis curve of the steel iron value. In this paper the analysis of motor is simulated with fixed magnet dimension. The motor performance would be improved more when the magnet dimension is changed to obtain the nearly saturated magnetic flux density along the stator tooth width.

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