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Reducing Cogging Torque in Permanent Magnet Synchronous Motor Using Ansys

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Abstract: *This paper presents design and performance analysis of Permanent magnet synchronous motor ofKW. The Permanent Magnet Synchronous Motors (PMSM) are high-performance electromechanical motion devices. The cogging torque of PMSM is reduced and the efficiency of motor is increased and then Finite element method (FEM) is used for determining the performance characteristics of motor. Permanent magnet synchronous motor, design and the reducing of its cogging torque is done on ANSYS/Maxwell 2D.In last motor is analyze by varying the lead angle in control circuit.*

Keywords - *Ansys software, cogging torque, FEM method, Permanent magnet synchronous motor*

I. Introduction

Permanent Magnet Synchronous Motor (PMSM) has better dynamic performance, smaller size and higher efficiency compared to other forms of motors. The power density of permanent magnet synchronous motor is higher than one of induction motor with the same ratings due to the no stator power dedicated to the magnetic field production. Nowadays, permanent magnet synchronous motor is designed not only to be more powerful but also with lower mass and lower moment of inertia.

Use of permanent magnets in motors improves the efficiency of motor approximately by 10%, owing to which permanent magnet synchronous motors (PMSMs) are used in varied applications. This is the major driving factor for the PMSM market. In addition, low power consumption and improved performance capabilities are advantages associated with the use of permanent magnets in the motors due to which these motors are used in green vehicles to reduce the fuel combustion. Therefore, in addition to the features of PMSM, widespread awareness of green and electric vehicle amongst the customers further supplements the growth of PMSM market.

Major factors influencing the PMSM market growth are rising need and demand for energy-efficient low power-consuming motors, growing demand of PMSMs in industrial and agricultural sectors, and increasing awareness towards the use of green vehicles. Furthermore, increasing emphasis on the maintenance and use of standard motors is likely to create opportunities for PMSM market growth in the future.[1]

This work aims at the reducing of cogging torque of PMSM and increase the efficiency of the motor with created parameters of the motor

Advantages-

- High Speed Operation – A PMSM motor can operate at speeds above 10,000 rpm under loaded and unloaded conditions.
- Responsiveness & Quick Acceleration – Inner rotor synchronous motors have low rotor inertia, allowing them to accelerate, decelerate, and reverse direction quickly.
- High Power Density – PMSM motors have the highest running torque per cubic inch of any DC motor.
- High Reliability – PMSM motors do not have brushes, meaning they are more reliable and have life expectancies of over 10,000 hours. This results in fewer instances of replacement or repair and less overall down time for your project.

II. Finite Element Method

There are number of techniques which have been developed to solve electromagnetic related problems not amenable to exact solution. The Finite element method is used to convert the complex partial differential equation into nonlinear algebric equation The finite element method can be applied to the vector Helmholtz wave equation, which is derived from the Maxwell's equations, or it can be derived from a scalar-vector potential formulation of the fields. There are variety of commercial geometrical modelling tools to accurately model any three–dimensional geometry and to generate the required mesh with any kind of elements such as triangles, tetragonals and hexagonals[2].

FEM involves the following for the solving a boundary value problem:

- Discretization of thedomain
- Derivation of the element equations
- Assembly of theelements
- Solutions of the system equations

III. Basic Mathemetical Model Of Pmsm

The mathematical model is similar to that of the wound rotor synchronous motor. As there is no external source connected to the rotor side and variation in the rotor flux with respect to time is negligible, there is no need to include the rotor voltage equations. Rotor reference frame is used to derive the model of the PMSM shown in figure1.

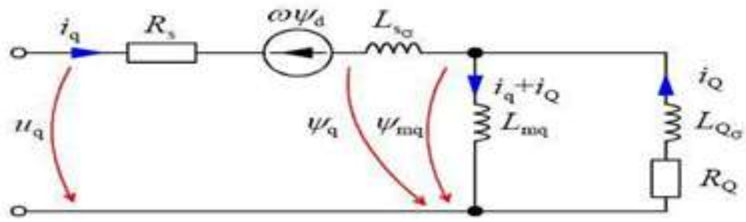

Figure 1: PM equivalent for q-axis

The electrical dynamic equation in terms of phase variables can be written as:

$\square a = R_a i_a + p\square a$ (1)

$\square b = R_b i_b + p\square b$ (2)

$\square c = R_c i_c + p\square c$ (3)

While the flux linkage equations are:

$\square a = L_{aa}i_a + L_{ab}i_b + L_{ac}i_c + \square ma$ (4)

$\square b = L_{ab}i_a + L_{bb}i_b + L_{bc}i_c + \square mb$ (5)

$\square c = L_{ac}i_a + L_{bc}i_b + L_{cc}i_c + \square mc$ (6)

Considering symmetry of mutual inductances such as Lab = Lba, self inductancesLaa = Lbb =Lcc and flux linkage λma = λmb = λmc = λm. Applying the transformations (1) and (3) to voltages, flux linkages equation (4)-(6), we get a set of simple transformed equations as:

$\square q = (Rs + L_q p) i_q + \square rL_d i_d + \square r\square m$ (7)

$\square d = (Rs + L_d p) i_d - \square rL_q i_q$ (8)

Ld and Lq are called d and q-axis synchronous inductances, respectively. ωr is motor electrical speed. Each inductance is made up of self inductance (which includes leakage inductance) and contributions from other two phase currents.

The electromagnetic torque Te can be represented as:

$Te = (3/2)(P/2)(\square miq + (Ld - Lq)idiq)$ (9)

It is apparent from the above equation that the produced torque is composed of two distinct mechanisms. The first term corresponds to the mutual reaction torque occurring between iq and the permanent magnet, while the second term corresponds to the reluctance torque due to the differences in d axis and q-axis reluctance (or inductance). The equation for motor dynami

$T_e = Jp\square r + B\square r + Tl$ (10)

IV. Basics Of Motor Structure Specification

Torque (T) generated by PMSM motor is depends on rotor diameter (D) and axial length of the rotor (L). It can be represented as

$T = KD^2L$ (11)

With equation (11) it can be understood that the Torque generated by a motor is mainly depends on diameter of rotor. As the diameter of rotor increases circumference area availability for permanent magnet increases.

It can be interpreted that if the axial length is double, Torque will also double at constant power [2]

Cogging torque is defined as the unwanted torque that is produced in the PM SM motor due to the interaction of the rotor magnets and slots and poles of the machine. The cogging torque reduces the average torque produced by the machine and introduces unwanted torque ripple in the PMSM motor. The expression for the cogging torque is given by

$$T_{cog} = -\frac{1}{2} \O g^2 dR/d\theta \qquad (12)$$

Where Øg is the air gap flux and dR/dΘ is the change in air gap reluctance with respect rotor angle. It is important to note that most techniques used to reduce the cogging torque will reduce the effective back EMF and hence the resulting mutual torque production.

V. Stator Design

Stator is the static part of any motor or generator. Table 1 shows the parameters of analyzing the design of PMSM. With the reference of table 1, our proposed stator design is mentioned On the basis of table 2.[4]

Table.1 basic parameter

SR.NO.	PARAMETER	VALUE
1	Rated power(w)	1500
2	Rated voltage(volt)	100
3	Rated speed(rpm)	3000
4	No. of pole	4
5	Frictional loss(W)	10
6	Windage loss(W)	2

The stator designed with the rated speed of 3000 rpm and it have 4 number of poles. The rated power of the stator is 1500 watts.

Table 2 proposed stator parameters

SR.NO.	PARAMETER	VALUE
1	Number of slot	12
2	Outer Diameter(mm)	120
3	Inner Diameter(mm)	62
4	Length of stator core(mm)	55
5	Number of slots	12
6	Stacking factor	.95
7	Conductor per slot	120

With the help of above mentioned parameters ststor is designed using Ansys software shown in figure 2. .

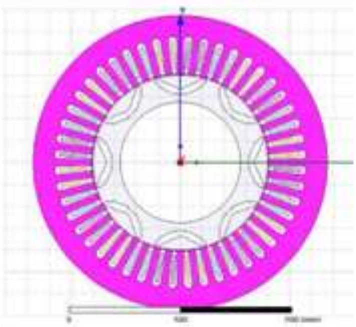

Figure 2: Design of stator using ansys

Slot parameters- The slot which is present in the stator dimension are given in table 3. [4]

TABLE 3. Slot Dimension

Sr. No.	PARAMETER	VALUE
1	H_s0(mm)	1.5
2	H_s2(mm)	9.4
3	B_s0(mm)	2.5
4	B_s1(mm)	11.41
5	B_s2(mm)	16.83

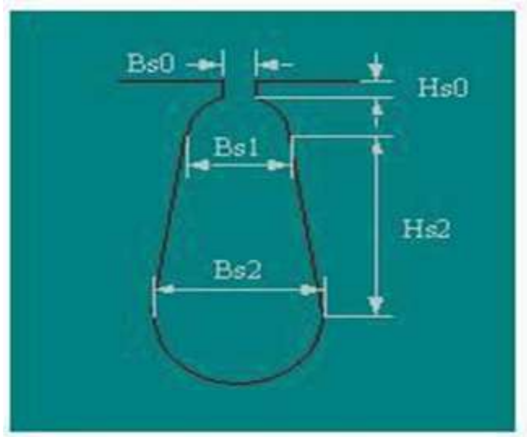

Figure 3: Slot Dimension

VI. Rotor Design

It is the moving component of the electromagnetic system in the electric motor or generator. For the rotor permanent magnet pole many shapes are given.

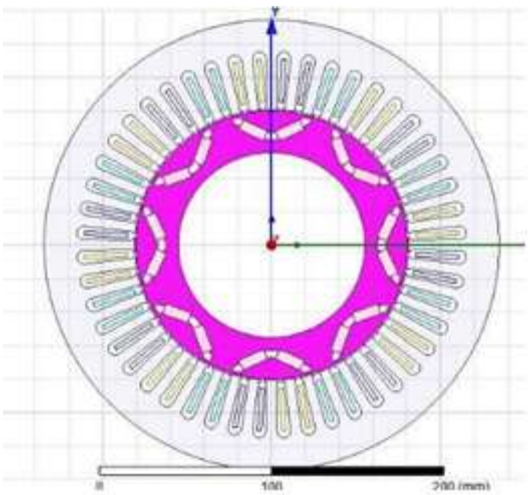

Fig.4. Rotor Geometry

Rotor parameters are given in table 4.

Table.4:rotor parameter

Sr.No.	PARAMETER	VALUE
1	Minimum air gap(mm)	1
2	Inner Diameter(mm)	18
3	Outer Diameter(mm)	60
4	Length of rotor(mm)	55
5	Type of steel	Steel_1008
6	Embrace	.85
7	Thickness of magnet(mm)	4
8	Magnet Type	NdFe35
9	Width of Magnet(mm)	36.73

In our proposed motor, the rotor designed with air gap of 1 mm and inner diameter of 18 mm. The rotor have the magnet and the thickness of the magnet is about 4 mm and the magnet type is neodymium magnet.[4,5]

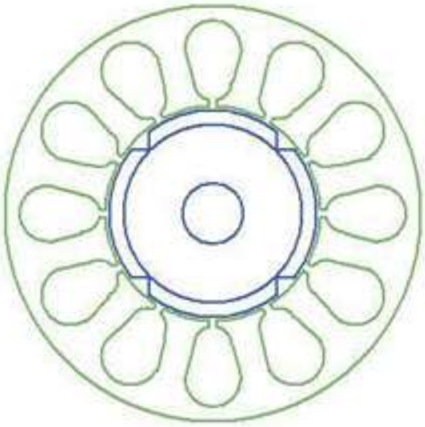

Figure 5: Cross-section view of Pmsm Vii.Permanent Magnet

A neodymium magnet also known as NdFeB, NIB or Neo magnet, the most widely used type of rare-earth magnet, is a permanent magnet made from an alloy of neodymium, iron and boron to form the $Nd_2Fe_{14}B$ tetragonal crystalline structure. Developed independently in 1982 by General Motors and Sumitomo Special Metals, neodymium magnets are the strongest type of permanent magnet commercially available. They have replaced other types of magnets in many applications in modern products that require strong permanent magnets, such as motors in cordless tools, hard disk drives and magnetic fasteners.

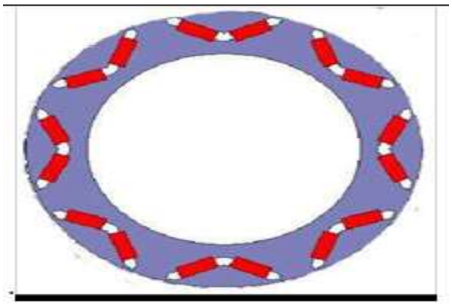

Figure 6. Reposition of magnets in our model

In our proposed motor the magnets are repositioned as shown in figure 6. By this grasping power of the magnet increases and also it reduces the certain losses.

Table.5. Other important parameter for motor

Sr.No.	PARAMETER	VALUE
1	Residual Flux Density(Tesla)	1.23
2	Coercive Force(A/m)	890000
3	Maximum Energy Density(kj/m^3)	273.675
4	Average Input Current(A)	15.94
5	RMS Armature current(A)	15.94
6	Armature Current	.55821
7	Frictional and Windage Loss(W)	10.38
8	Iron core Loss(W)	.002127
9	Armature Copper Loss(W)	10.38
10	Transistor Loss(W)	68.526
11	Diode Loss(W)	4.69
12	Total Loss(W)	94.5853
13	Output Power(W)	1499.3
14	Input Power(W)	1594.52
15	Efficiency	94.0681
17	Rated Torque(N-m)	5.1074
18	Maximum Output Power(W)	6062.87
19	Air Gap Ampere Turn(A.T)	573.567
20	Magnet Ampere Turn(A.T)	-1218.1

The motor is designed with the above specification parameters and the simulation of the model is executed in the Maxwell software is shown in figure 7.[6]

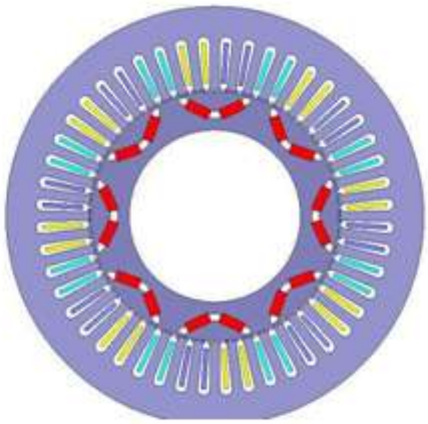

Figure 7:Design of motor

The analysis of motor is done on the basis of simulation in Maxwell 2D and figure 8 shows the mesh formation at specific time of rotor position..

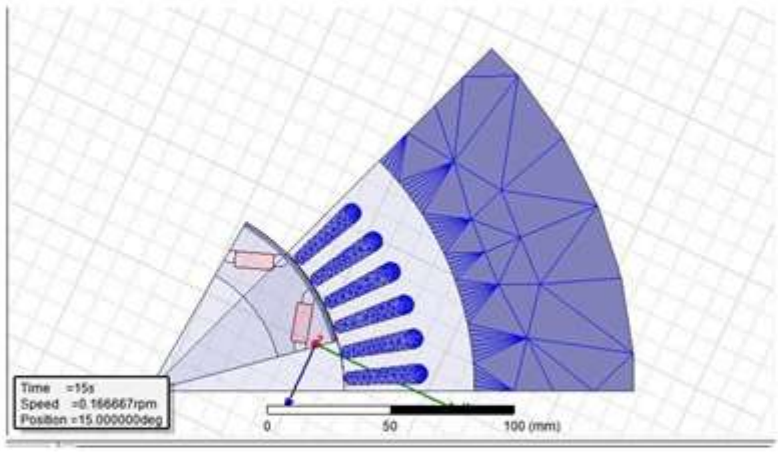

Figure 8: Mesh information

Motor torque generated by the motor at different time is shown in Figure 9.

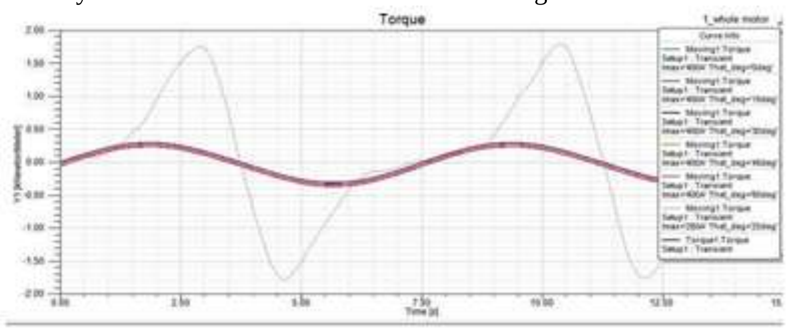

Figure 9: Output

Analysis after decreasing the cogging torque of the permanent magnet synchronous motor. For improving motor performance lead angle is varying and the change in motor performance is analyzed. After changing motor lead angle efficiency of motor is increased. Lead angle shows how early the phase voltage is injected. When lead angle increases, phase current excites the earlier winding. As each phase current has the same phase angle as each phase back emf, the PMSM motor gives the given torque demand while needing a lower demand current and achieves higher efficiency as copper loss is reduced. On lead angle 15 degree the motor rotated is shown in figure.10

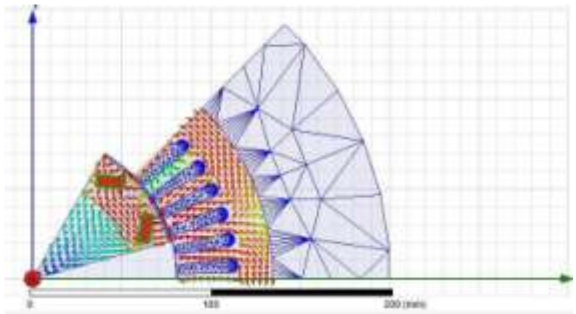

Figure 10: PMSM with lead angle 15 degree VIII.CONCLUSION

A detailed modeling of PMSM has been performed. To obtain the efficiency increased PMSM machine is designed based on the increasing of stator slots, changing of stator slots and placing of magnets in the cross way. This paper shows that motor gives considerably good efficiency at rated speed and rated torque. Motor is design in ANSYS/Maxwell 2D. After designing of motor, analysis is done positive by varying the lead angle of control circuit. It is seen that when the lead angle is increased from 0 degree to 15 degree efficiency of the Permanent Magnet Synchronous Motor is increased.

Thus it can be concluded that the efficiency of the permanent magnet synchronous motor is increased by reducing cogging torque based on the above designed machine.

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