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Finite Element Analysis of Permanent Magnet Brushless DC Motor

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Abstract - *This paper presents mathematical modelling and FEM analysis of PMBLDC motor. The machine parameter of stator and rotor parts including torque speed characteristics and magnetic analysis are investigate by FEM analysis and analytically. The mathematical modelling of PMBLDC is carried out by the MATLAB software and FEM analysis is carried out by the ANSOFT MAXWELL software. Parameter of machine is calculated with high accuracy and precision. Perfect analysis can be achieved by comparing the results from above both processes of motor design. The analysis demonstrates the effectiveness of the proposed machines design methodology. PMBLDC motor with 550 Watt rating and 1500 rpm rated speed has been designed and the result of efficiency torque and cogging torque has been generated*

***Key Words*: Permanent Magnate Brushless DC Motor; Finite Element Analysis; Efficiency.**

1. INTRODUCTION

There are two unique reasons for the improvement of the machine. One of reason is to collaborating the increase the use of computers system for controlling the machine and another reason is to use the new technology for controlling the mechanical motion by use of the power semiconductor and intelligence device. By use of this controlling strategy we can adjust the speed of machine.[8] Due to adjusting the speed energy saving is possible and transient can be reduced.

Due to these reasons of controlling the machine we have to design the new machine strategy for use the new control strategy. Too many machines are design for use the new enabling control strategy and Permanent Magnet Brushless Direct Current (PMBLDC) Motor one of them. PMBLDC motor has Stator and Rotor construction as the conventional motor. The conventional motor has brush and commutator arrangement for supplying the power to the rotor. But the PMBLDC motor has no brush-commutator arrangement, it has the Permanent Magnet at the Rotor side and the stator is conventional construction with different control strategy.

According to the position of the rotor the stator excitation takes place and this control is known as position control strategy. The stator and rotor of the PMBLDC is as shown in fig 1 and fig 2.

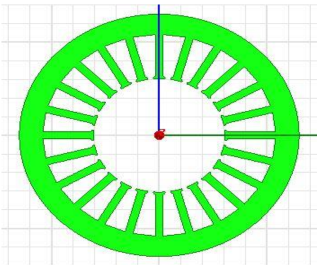

Fig -1: Stator diagram

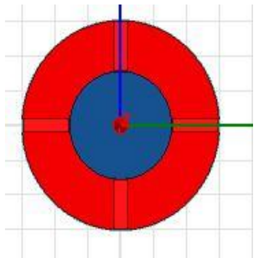

Fig -2: Rotor diagram

This very unique machine has wide era of application. Application is categorized according to the loads values and positioning control application. The constant load, varying load application and positioning control application has use the PMBLDC motor. This machine has very high efficiency, good position control, wide range of speed, silent operation and very high reliability as well as high power density. The PMBLDC is also used in military and automotive applications.

According to the back emf we can say that the machine is PMAC or PMDC. Weather the Back emf is sinusoidal type than the machine is PMAC machine and if trapezoidal type than the machine is PMDC.[1]

There are two type of PMBLDC motor in which one is radial flux and other is axial flux PMBLDC. In Radial Flux PMBLDC flux passes perpendicular to the axial and in Axial Flux PMBLDC flux passes through parallel to the axial so, it is called as axial flux PMBLDC. The radial flux PMBLDC further classified in to four part are (1)Surface Mounted PM motor with inner rotor,(2) Surface Mounted PM motor with outer rotor, (3)inset motor,(4)buried PM. Buried PM motor are also classified into(i) V-shaped Permanent magnets motor(ii) Tangentially magnetized permanent magnets motor.

2 mathematical modeling of PMBLDC machine

2.1 stator representation

There are some parameters to consider as the fixed parameter which not varies with the calculation. Due to the calculation the parameter we acquired that are known as variable parameter. We can derive the equation from the stator and rotor diameter and the other important parameter and the formulas and the equation are as follows:

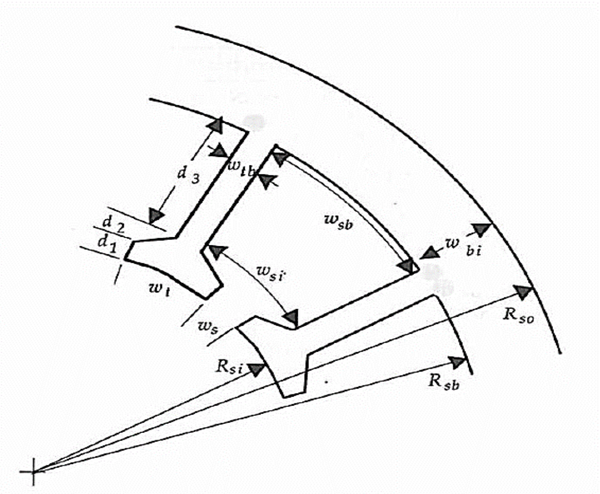

Fig -3: Stator configuration and dimensions

Table -1: fixed parameter

Fixed parameter	
R_{so}	Stator outer radius
R_{ro}	Rotor outer radius
L	Axial length of machine
g	Air gap
l_m	Magnet thickness
N_m	Number of magnet pole
N_s	Number of slot

Back iron width W_{bi}

$$w_{bi} = \frac{\Phi_g}{2B_{\max}k_{st}L}$$

Tooth width at bottom W_{tb}

$$w_{tb} = \frac{\Phi_g}{N_{sm}B_{\max}k_{st}L} = \frac{2}{N_{sm}}.w_{bi}$$

Rotor inside radius R_{ri}

$$R_{ri} = R_{ro} - l_m - w_{bi}$$

Stator inside radius R_{si}

$$R_{si} = R_{sb} - d_s = R_{ro} + g$$

Tooth width at surface W_t

$$w_t = \tau_s - w_s$$

Slot width at bottom

$$w_{sb} = R_{sb}\theta_s - w_{tb}$$

$$d_s = R_{sb} - R_{ro} - g$$

$$d_s = d_1 + d_2 + d_3$$

$$d_1 + d_2 = \alpha_{sd} w_{tb}$$

2.2 torque and efficiency

The torque is depend on the size of machine and the basic equation of the torque is as follows:

$$T = kD^2L$$

Where D is the diameter of machine and L is the length of machine and k is constant

Now due to the different parameter the torque developed in the machines

$$T = N_m k_d k_p k_s B_g L R_{ro} N_{spp} n_s i$$

Ohmic loss

$$P_r = N_{ph} I_{ph}^2 R_{ph}$$

Where R_{ph} is phase resistance, I_{ph} is phase current, N_{ph} is number of phase

Core loss

$$P_{cl} = \rho_{bi} V_{st} \Gamma(B_{max}, f_e)$$

Where ρ_{bi} is mass density of stator material (kg/ m^3), V_{st} Is stator volume $\Gamma(B_{max}, f_e)$ =core loss density (watt/kg) of stator material at B_{max} and frequency f_e

Efficiency η at rated torque and rated speed is

$$\eta = \frac{T\omega_m}{T\omega_m + P_r + P_{cl} + P_s}.100\%$$

Where P_s is the stray loss, composed of wind age, friction, and other less dominant loss components

2.3 Finite Element Method

The Finite Element Method is first studied by R. W. Clough in 1960$_s$.The Finite Element Method is the numerical method to solve the problem of physics as well as engineering. By use of this technique we can study the saturation effect, hysteresis effect, magnetic effect, material anisotropy and much more. This technique separated the machine body into small element and at every element numerical integration is applied and after that it concludes to the result. There are some basic equation related to electromagnetic analysis is below:

$$\nabla \cdot \vec{B} = 0 \quad ; \quad \nabla \times \vec{H} = J$$

$$\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial T} \quad ; \quad J = \sigma(\vec{E} + v \times \vec{B})$$

$$\vec{B} = \mu_0(\vec{H} + \vec{M})$$

B= flux density μ=magnetic permeability

σ=electrical conductivity ν=velocity

E=electrical field intensity J=current density

H=magnetic field intensity M=magnetization

3. Simulation results

550W, 1500 RPM, 3phase, 4 pole PMBLDC motor is taken study purpose. The stator and rotor outer radius is 65mm and 30mm respectively. From the calculation and the equation of the machine parameter the efficiency and the torque is to be calculated. After that the uses of FEM tool the efficiency and the torque is to be calculated.

Table -2: Output of the analytical

Parameter	**value**
stator inner radius(mm)	30.5
tooth width at surface(mm)	5.5
width of stator back iron (mm)	11
tooth width at bottom(mm)	3.7
rotor inner radius(mm)	15.5
slot width at bottom(mm)(Wsb)	10.5
ds= conductor slot depth(mm)	23.4
Ohmic loss (Watt)	74.073
core loss(Watt)	29.93
T= torque(Nm)	**3.5014**
efficiency	**81.60%**

According to the calculated parameter the FEM tool the design is to be done. The design of the PMBLDC for FEM is as shown in fig 4, 5.

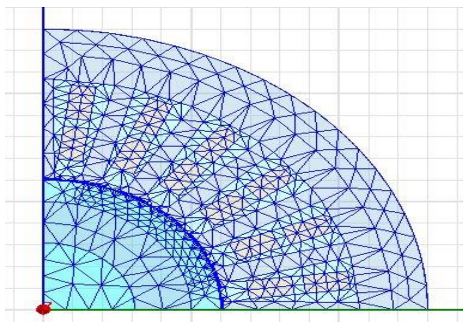

Fig -4: mash analysis of PMBLDC

After run the simulation of the FEM the rotor rotate up to certain degree of rotation and is as shown below.

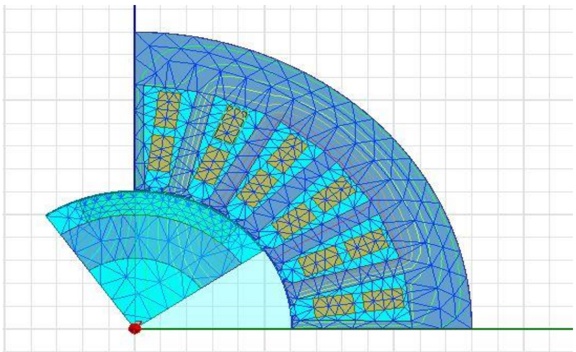

Fig -5: flux line and rotate rotor

The efficiency and the torque are calculated and cogging torque waveform is as shown in fig 6, 7, 8 respectively.

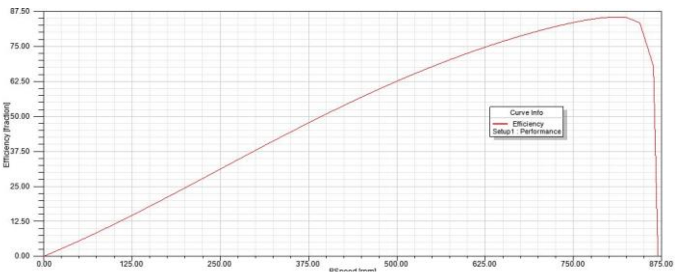

Fig -6: efficiency of PMBLDC

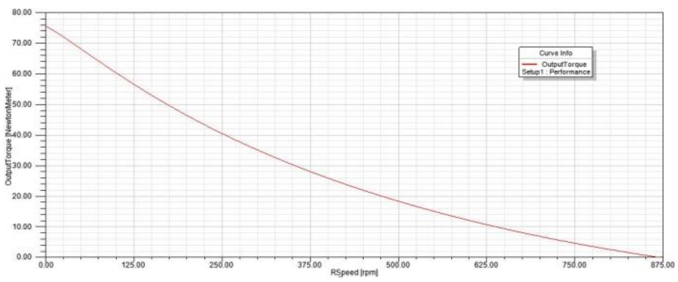

Fig -7: torque of the PMBLDC

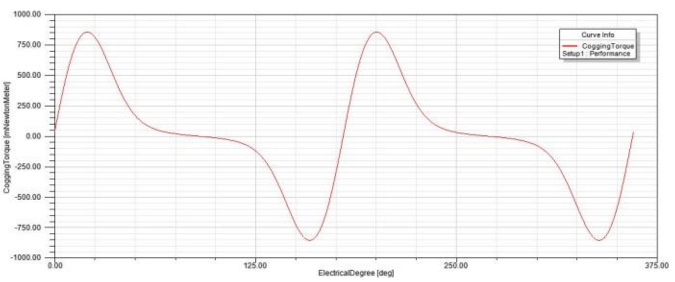

Fig -8: cogging torque of PMBLDC

Comparison of the output of the FEM and Analytical solution gives the exact idea about the FEM technique that how accurate it is.

Table -3: comparison of two method

Speed	efficiency	
	analytical	FEM
1200	76.85	79.36
1500	81.601	84.67
1700	83.63	88.51

4. CONCLUSIONS

In this paper mathematical modelling and FEM analysis of PMBLDC motor is carried out. The machine parameter of stator and rotor parts including torque speed characteristics and magnetic analysis are analysed. The mathematical modelling of PMBLDC is carried out by the MATLAB software and FEM analysis is carried out by the ANSOFT MAXWELL software. Than both way the efficiency is comprise with high accuracy and precision. Perfect analysis can be achieved by comparing the results from above both processes of motor design. The analysis demonstrates the effectiveness of the proposed machines design methodology. PMBLDC motor with 550 Watt rating and 1500 rpm rated speed has been designed and the result of efficiency torque and cogging torque has been generated

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