Design and optimization of dc brushless permanent magnet motor

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Abstract

Electric motors with lots of applications in various sectors of industry have unique features such as high reliability, high efficiency, quick acceleration, and are found in very small sizes. Brushless DC motors meet these requirements well. In this study, the design of a brushless DC motor speed limits for the particular application at 1800 rpm was provided that can be equivalent to 140 watts output. The present study intends to increase the power density, efficiency and to reduce engine weight by using the finite element method. According to the analysis of the existing motors and parameter extraction, they were compared using software for high electromagnetic torque and low weight. In this article, we have focused on the permanent magnet by testing different types of magnets and comparing the results of finite element analysis. The existing magnets were made of ceramics with the lowest density, but the permanent magnet in software method has the highest energy density.

Keywords: brushless DC motors, optimization, finite element method, new structure.

1. Introduction

Due to the needs of society, and to reduce the price of permanent magnets, consumers seek to replace permanent magnet motors with other engine types. Weight, size, efficiency and reliability are important factors in the selection of electric motors required in industry. The power output of the engine and its speed is directly proportional to the volume of magnetic materials for cars. Thus, increasing engine speed and its dimensions will lead to weight loss. The design for electric motors usually involves two main steps:

1- The main dimensions and parameters for calculation engine
2- Predicting engine performance

In the first phase, the engine dimensions such as length and outer diameter of the stator core must be selected. A number of quantities related to engine performance such as torque and power output should also rest or comply with international standards and comply with the requirements of the requesting electric motor. In this study, the design of a brushless DC motor speed limits for the particular application at 1800 rpm equivalent to 140 W output was provided. At first, the numerical model and governing the design of this engine have been studied and then according to the equations, flowcharts for engine design have been presented. External rotor motors of the type have been put on magnets using the rotor surface and the engine type is called SMPM.

2. Motor Design

In this section, we explain the geometry, magnetic and electrical requirements and discuss about the engine design. According to Figure 1, we can determine geometric parameters.

In an electric charge and with certain magnetic specific rotor diameter, the diameter of the end machine could be increased and the number of poles could be reduced.

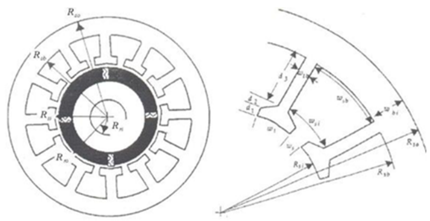

Fig.1.Topology of radial flux motors with geometry

$$w_{ry} = w_{sy} = \frac{2.\pi.B_g.R_{si}}{4.p.B_p} \quad (1)$$

Relations Is the radius of the following:

$$\begin{aligned} R_{sb} &= R_{so} - w_{bi} \\ R_{si} &= R_{sb} - d_s = R_{ro} + L_g \\ R_{ri} &= R_{ro} - L_m - w_{ry} \end{aligned} \quad (2)$$

Pole and pole angular dimensions can be calculated according to the following formula linked together:

$$\theta_p = \frac{2\pi}{N_m}, \quad \tau_p = R_{si}\theta_p \quad (3)$$

Steps in the inner radius of the rotor coil can be obtained through the following equation:

$$\tau_c = \alpha_{cp}\tau_p \quad (4)$$

2-1. Choose a rotor topology:

In the outer tour is selected designed to work with permanent magnets at high speeds. To prevent magnets from detaching from the rotor by centrifugal forces, the rotor surface is enclosed in a thin metal layer and if the outer rotor needs this metal cylinder, six different permanent topology rotors magnets are shown

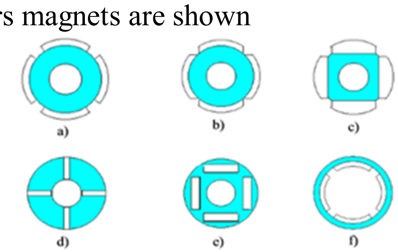

Fig. 2. Topology of permanent magnet rotors

2-2. specific motor design analysis:

In this section a direct current brushless permanent magnet motor with intermittent function 24 V, 140 W of output power allowed 180 W maximum power and 1,800 rpm examined:
There are a number of limitations discussed in engine design:

1) Flux density in the air gap: The amount of flux in the air gap is usually between 4.0 to 7.0 Tesla, respectively. In this design we selected an amount equal to 58/0 Tesla to carry the investigation.

2) Air gap width of 1 mm is assumed initially.
3) Bow step towards the poles

4) As mentioned above, 3-phase motors, 12 slots, and 8 poles have been selected.
5) No-load speed is four percent more full load speed than the 4/10 radians per secon

Assuming that all magnetic flux lines generated by the magnet, with the exception of flux, we pass through the gap:

$$B_m A_m = K_1 B_g A_g \quad (5)$$

The number of armature conductors is calculated as follows elderly:

$$Z = \frac{3T}{DLB_g k_w I_a} = \frac{3\times 64.2}{0.052\times 0.009\times 0.58\times 1.9\times 5.9} = 6300$$

The slot pitch and density per rack is:

$$\tau_s = \frac{\pi D}{N_s} = \frac{\pi\times 52}{12} = 13.61 \quad (mm)$$

$$B_{tr} = \frac{B_{av}\pi D}{w_{tr}S} = \frac{0.945\times\pi\times 52}{7\times 12} = 1.83 \quad (T)$$

Table 1.Values View Magnet

The maximum energy	Angle of deviation	Step	Number	Permittivity Back	Density	Curie temperature	The temperature coefficient	Operating temperature	Grade
253	—	25	8	1.1	4.7 - 5.7	310	11	80≤	N35
kJ/m^3	Deg	mm	—	—	gr/cm^3	$^\circ C$	$\%/^\circ C$	$^\circ C$	—

2-3. losses:

Stator reactance resistance is fixed against the 0.3 Ohms at 25 degrees, respectively. As a result, we have:

$$p_{cu} = R\,I^2 = 0.3\times(5.9)^2 = 10.44 \ (Watt)$$

Weight teeth of the armature and the core can be calculated as follows:

$$G_c = \frac{\pi}{4}[D^2-(D_i+2d_s)^2]l_{ia}\gamma$$
$$= \frac{\pi}{4}[(0.25)^2-(0.052+2\times0.0554)^2]\times0.95\times0.009\times7750 = 0.21 \ (k$$

And, efficiency is equal to:

$$\eta = \frac{p_a}{p_a+p_{cu}+p_{core}+p_s}\times100\% = \frac{140}{140+10.44+0.86+1.4}\times100\% = 91.6$$

3. Motor design using the software

Software RMxprt, software for the design and analysis of electric machines was provided by ansoft. Input featuring the main electrical parameters (power, frequency, and voltage) and the geometric dimensions of the machine (external and internal diameter of the stator, the rotor and the stator core and the rotor outer and inner diameter) are identified. The stator slot in accordance with Figure 3 and Table 3 shows the parameters given to the application.

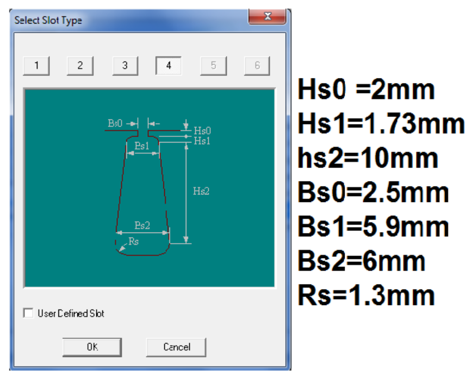

Fig.3. The stator slot design

According to the proposed numerical relationships, an optimization method to obtain unknown parameters can be defined. The purpose of optimization method is to help the engine to get the lowest possible weight. Selection goal in this research enabled Motors weight that should be in the least possible amount. The copper losses and weight constraints are limited by magnets. It should be noted that for the mechanical strength, no magnetic saturation and calculating efficiency is also taken into consideration regarding the constraints required.

Coil design shown in Figure (4) with single-layer winding three-phase windings together with step 3 represents almost all cars brushless permanent magnet.

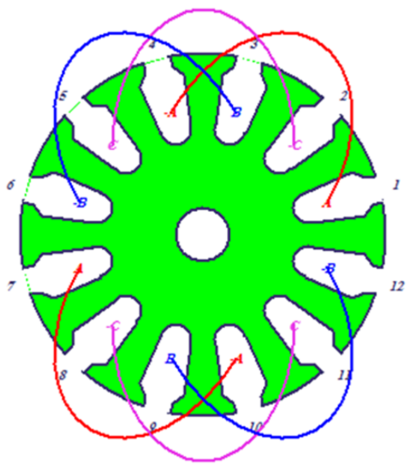

Fig.4. The coil provided with Applications

Figure 5 shows, the waveform of the magnetic flux density gap shown in terms of electrical angle. Curved trapezoidal form and the range is 58.8. Engine efficiency is also in the form (6).

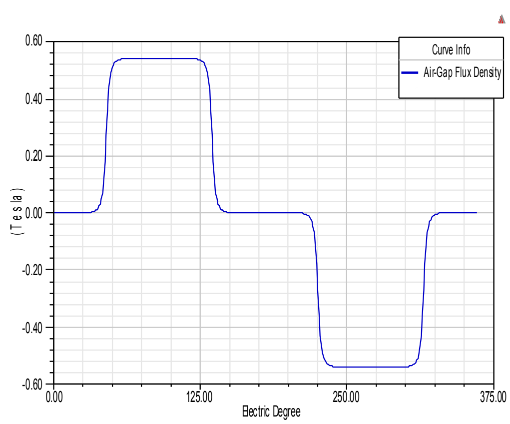

Fig.5. The air gap flux density

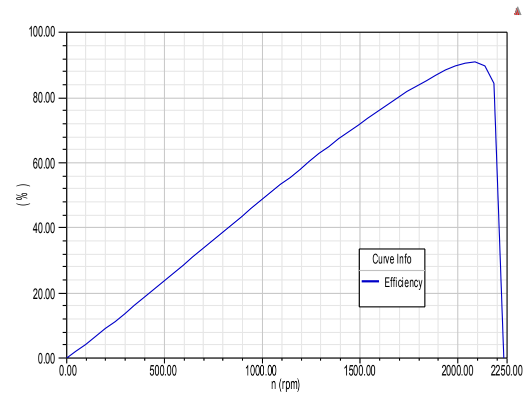

Fig.6. Designed motor efficiency

4. Finite Element Analysis

Here no-load analysis is done on motor and it is assumed that the rotor is stationary (static magnetic analysis). After the fluid is injected into the stator windings and target only modeling engine is in no-load mode, figure 7 shows the motor flux lines (due to the symmetry of a fourth cut). The magnetic flux lines were highest and it passes after passing through the air gap. The stator teeth and stator yoke their way through the surrounding magnets and rotor closes. Figure 8 shows a two-dimensional view of a simulated motor show.

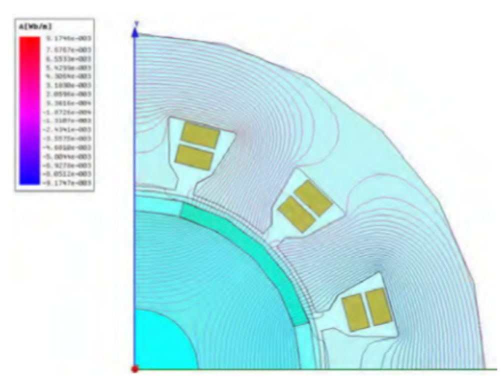

Fig.7. Motor no-load flux lines

Table 2.Motor design parameters

Analytical Solution	unit	parameter
3	-	Number of phases
8	-	Number of poles
12	-	Number of tracks
170	Watt	Maximum power output
140	Watt	Allowed output power
0.64	Nm	Moment of inertia
24	V	Terminal voltage
1	mm	Air gap
1800	RPM	speed
23.3%	-	Track occupancy rate
0.58	T	Flux density in the air gap
9	mm	The inner diameter of the stator
52	mm	The outer diameter of the stator
9.4	mm	The thickness of a router
127	mm^2	The area of copper per slot
0.412	mm	Wire diameter
6	mm	The height of the groove
9	mm	During the motor armature
0.00693	$Kg.m^2$	Mass inertia of the rotor
10.44	watt	Copper losses
0.86	watt	Core loss
91.68%	----	Efficiency

Table 3.Parameters to the application

amount	parameter	amount	Parameter
Automotive	Operation	4	Number of poles
170	output power	Outer	Rotor position
24	Output voltage	1800	Speed
Nd Fe B	Type of magnets	56	The outer diameter of the stator
9	During the roto	0.95	Stacking factor
M19-24G	Iron rotor	M19-26G	Stator iron
0.5	Embrace	12	The number of slot
0.4	Wire diameter	2	Qatar Magnets
4.7	The thickness of the magnets	6300	The number of armature conductors
Be fixed	Type of bar	brushless	Type of car

5. Conclusion

According to the simulation results and many articles in the field of three-phase brushless direct current motors it is well known that multi-phase brushless permanent magnet direct current motor has a much better performance characteristics than conventional three-phase motors. Torque and speed of the commutation phases have fallen sharply. The engine is a good choice for military applications.

Using standard electromagnetic field analysis, a brushless permanent magnet motor was designed for high-speed applications sample design engine satisfactory results in practice showed that the results obtained are as follows:

1. In Speed of 1800 rpm the engine is designed for this value, the amount of engine power and efficiency by solving analysis and simulation was a good match.
2. According to analytical results and providing weight-optimized software engine at high speeds suitable for users in the table 4 has come; engine weight is reduced compared to existing engines.
3. Probably due to the high efficiency of brushless and brush motors we observed a loss about 78% to 98%. The design and calculation efficiency was about 91% and the design software value increased to more than 91%. The accuracy of the results was obtained
4. By testing with different types of magnets and comparing the results of finite element analysis. The existing magnets made of ceramics with the lowest density, but the permanent magnet in software method has the highest energy density.

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