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Design of disk type PM synchronous generator based on halbach

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Abstract. This paper expounds the application merits of disk type PM synchronous generator in small-scale wind power generation .The characteristics of the disk type PM synchronous generator were analyzed and 8P, 200W disk type generator with 90 degree Halbach magnet structure was designed. Simulation and calculation are carried out by using finite element method. By comparing the 90 degree Halbach magnet structure and the traditional magnet structure of the disk type generator, the results shows that the 90 degree Halbach magnet structure can improve the air gap magnetic density, reduce the leakage of main magnetic circuit and the loss.

1 Introduction

Disc type permanent magnet synchronous motor with axial flux characteristics plays an irreplaceable role in many fields. Various studies have been made about the axial permanent magnet motor in the application of high speed motor and generator [1-4], also it has a wide application in electric vehicle [5-6], flywheel energy storage [7], driven ship elevator [8], and ship drive[9]. A coreless axial-flux machine with Halbach structure in direct-drive wind power generation field has the following advantages: (1) small axial size, high power density, simple structure; (2) coreless structure has no cogging effect which can effectively reduce the motor vibration and noise caused by the cogging; (3) the magnetic pole has a special Halbach structure which hold better sine degree of air gap magnetic density, meanwhile, avoiding the additional loss caused by harmonic. Thus, the study on the coreless disc generator with Halbach structure in the direct drive wind power generation field has important practical significance.

The main contributions of this paper can be summarized as follows. Regarding to the Halbach array structure of coreless double disc rotor permanent magnet generator, the structure and corresponding design features were analyzed. And, the three dimensional electromagnetic finite element calculation of the designed 8P and 200W disk motor is carried out ; The characteristics of magnetic field distribution of motors are studied through the analysis of the finite element field plots results and numerical results; The influence of different Halbach magnetic pole structure and magnetic pole thickness on the air magnetic flux and peak value is studied as well.

2 Structural design of coreless, double external rotor disc type permanent magnet generator with Halbach array

2.1. Structure of magnetic circuit Based on Halbach

Coreless double exterior rotor disc type generator is composed of the pole, the back iron , armature windings, bearings and other structures. Magnet is made of special structural configuration of Halbach array and it is attached to the back of a certain thickness of ductile iron that has a strong magnetic permeability. Armature winding consists of multi-strand wire wrapped package in accordance with a certain pitch. The structure of disc type generator with Halbach array shown in figure 1. As shown in figure.1（a）, each magnetic pole is composed of axial magnetization pole a and auxiliary magnetic pole b which is perpendicular to a. Every four different polarization direction of the magnetic poles formed a set of loop. The material of back iron is made of nodular cast iron which can ensure the strength of the rotor as well as lower the cost of machine. Windings were wrapped by using a tool specially designed for this machine. After the windings were made we encapsulated the windings into epoxy resin which can leave out the iron core and solve the problem of cogging torque when the speed of wind power generate is low.

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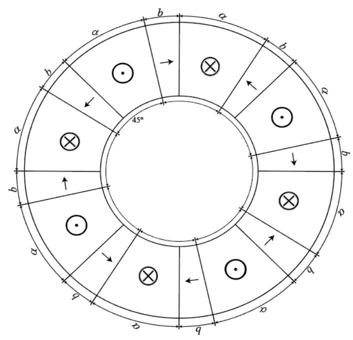
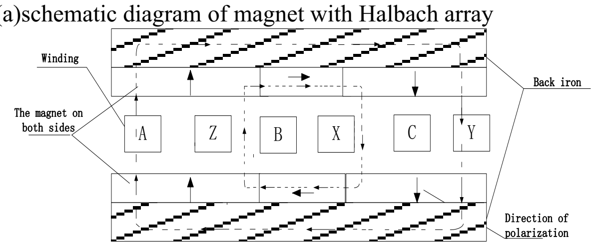


(a)schematic diagram of magnet with Halbach array



(b) a pair of magnetic pole expansion

Figure 1.the expand structure of disc type generator with 90° Halbach array

As shown in figure 1(b),the path of main magnetic flux are marked with dotted lines. In figure 1 (b), there are a pair of upper and lower rotor NS poles respectively. It is shown in the figure that the main magnetic circuit starts from the N pole on the right side of the rotor to the S pole in lower rotor through the winding, and then gets to the N pole on the left side of the rotor. Then it gets through the wingding again into the S pole in upper rotor, and finally returns to the N pole on the right rotor to complete a closed magnetic circuit.

2.2. Determination of inner and outer diameter of double external rotor disc type generator

The direction of magnetic field line through stator winding is axial direction and the conductor which parallel to the pole is the effective part. The position of a single conductor in the plane is represented by r and θ as shown in figure 2.

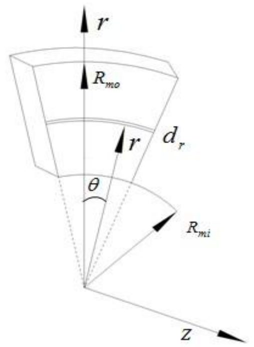


Figure 2. electromagnetic calculation diagram

Air gap magnetic density at the mean radius of generator is represented by $B_\delta(\theta)$. The mechanical angle is represented by Ω .The average electromotive force of each conductor can be expressed by[4] :

$$\frac{p}{\pi}\int_0^{\pi/p} e d\theta = \frac{1}{8}\Omega(D_o^2 - D_i^2)\frac{p}{\pi}\int_0^{\pi/p} B_\delta(\theta)d\theta = \frac{1}{8}\Omega B_{\delta av}(D_o^2 - D_i^2) \quad (1)$$

I_Φ is the effective value of phase current and E_Φ is effective value of phase voltage. Phase number is represented by m . Air gap flux density is represented by B_δ .Average air gap magnetic density in each pole distance is $B_{\delta av} = \alpha_i B_\delta$. The power of the generator p can be expressed by[4]:

$$p = mE_\Phi I_\Phi = \frac{\pi}{2\sqrt{2}} mE_{\Phi av} I_\Phi \quad (2)$$

The electrical load A_{av} at mean radius of the generator can be expressed by[4]:

$$A_{av} = \frac{4mNI_\Phi}{a\pi(D_0 + D_i)} \quad (3)$$

Put formula (3) into formula (2) :

$$p = \frac{\pi^3}{960\sqrt{2}} n\alpha_i k_w B_\delta A_{av}(D_o^2 - D_i^2)(D_o + D_i) \quad (4)$$

Set $D_o = \gamma D_i$

$$p = \frac{\pi^3}{960\sqrt{2}} n\alpha_i k_w B_\delta A_{av}(1 - \frac{1}{\gamma^2})(1 + \frac{1}{\gamma})D_o^3 \quad (5)$$

Set D_o, A_{av} and B_δ as constant and γ as the variable. Taking the derivative of the last formula, it can be seen that the output is maximized when the Ratio of inner and outer radius is set to$\gamma = D_o / D_i = \sqrt{3}$ [10]。Also the motor inertia, the magnetic flux leakage factor, efficiency and other factors should be considered synthetically. Generally speaking, the ratio of inner and outer diameter of the axial flux disc type permanent magnet generator is between 1.5-2.2 [11].

3 Magnetic field simulation

3.1. Basic parameters of generator

The rated speed of the disc type generator is 500 rpm, and alternating current with 50Hz is desired when the speed is between 350 rpm and 500 rpm. According to formula $p = \frac{60f}{n}$, the values of p range from 6 to 8, and it set to 8 in this article. The basic parameters of double exterior rotor disc type generator is shown as Table 1.

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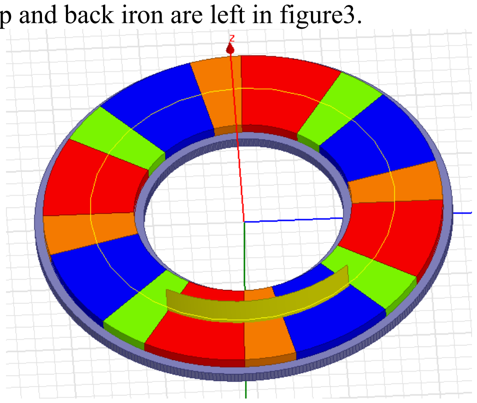
Table 1. The basic parameters of double exterior rotor disc type generator.

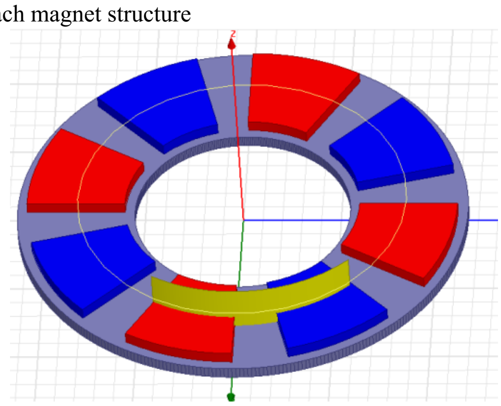
Item	Value
Rated Power/ W	200
Rated Voltage/ V	50
Rated Speed/ rpm	500
Poles	8
Rated Frequency/ Hz	50
Rotor Inner Diameter/ mm	110
Rotor External Diameter/ mm	230
Rotor Back Iron Thickness/ mm	6
Halbach Degree	90°
Magnetic Materials	NdFeB N50

3.2. Simulation and analysis of magnetic field of disk type generator

The 3-D model of disc type generator can be build based on the parameters given in Table 1 and the simulative calculation for electromagnetic field can be made. The finite element model of generator is shown in figure3. Halbach magnet structure is shown in figure3 (a) and traditional pole structure is shown in figure3 (b). In order to observe the air gap flux density only the lower Halbach pole group and back iron are left in figure3.



(a) Halbach magnet structure



(b) traditional magnet structure

Figure 3. finite element model of disk type generator

The section of the center line in Figure 3 is the position of the magnetic field analysis. After the calculation, the scalar diagram corresponding to the section in figure 3 is shown in figure 4. The air gap magnetic density of the 90 degree Halbach magnet structure and the traditional magnet structure all have the characteristics of uniform distribution. In the case of the Halbach magnet structure, the maximum magnetic density of the back iron is about 1.8T. In the case of the traditional magnet structure, the maximum magnetic density of the back iron is about 2.2T which presents the saturation phenomenon. Because of the magnetic flux is shared by the he Halbach magnetic pole structure, the magnetic density in the back iron part is small in the case of Halbach magnet structure.

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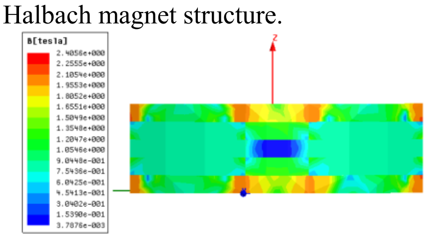
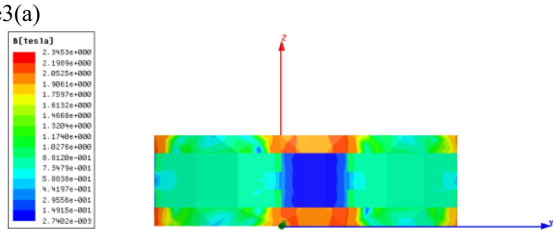


(a) the magnetic flux density corresponding to the section in figure3(a)



(b) the magnetic flux density corresponding to the section in figure3(b)

Figure 4. magnetic density distribution map of the disk type generator with Halbach magnet structure or traditional magnet structure

3.3. Disk type generator air gap magnetic density of Halbach magnet structure

For easy quantitative analyzing the air gap magnetic density, it draw a center line of the air gap that direction is perpendicular to the axial in the middle of the air gap as shown in figure 3. The pole-arc coefficient of the magnet is 30°/45°.In other words , the axial magnetization magnetic pole angle is 30 degrees. Axial magnetic density of the air gap on the center line of the curve is shown in figure 5 computed by the magnetic

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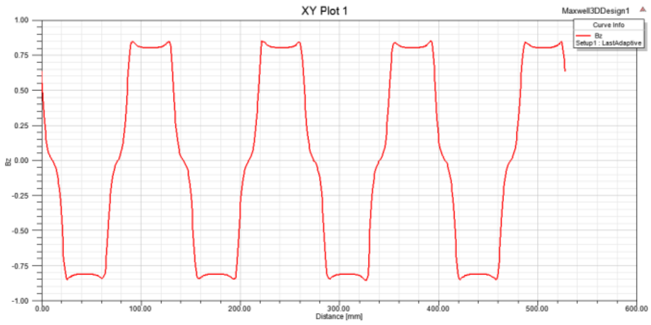
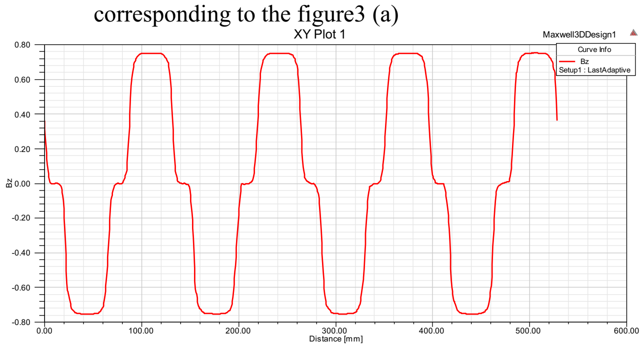
field. As can be seen from figure 5,axial magnetic density vector curve has four peaks and four low ebb. It meets the characteristics of the 4 S and 4 N poles of the disc type generator. In the case of the Halbach magnet structure which is corresponding to figure 3(a), The range of the magnetic density peak is 0.80T-0.85T. In the case of the traditional magnet structure which is corresponding to figure 3(b), The range of the magnetic density peak is 0.72T-0.76T. The width of the magnet on the air gap center is 43mm. In the case of the Halbach magnet structure, the peak width of air gap magnetic density is about 41mm. In the case of the traditional magnet structure, the peak width of air gap magnetic density is about 26mm.



(a) air gap center line magnetic density curve corresponding to the figure3 (a)



(b) air gap center line magnetic density curve corresponding to the figure3 (b)

Figure5. magnetic density curve when the axial magnetization magnetic pole angle is 30 degrees

4 Conclusion

In this paper, the design of the disc type generator is studied from the aspects of the structure and application of the small direct drive wind power generator. The calculation formula of the stator winding of the disc motor is induced, and Halbach magnet structure stator magnetic circuit is designed. Using finite element method to analyze the magnetic field of disk type generator with 90 degree Halbach magnet structure and traditional magnet structure, we can get the following conclusions:

1. In the case of the Halbach magnet structure, the maximum magnetic density of the back iron is about 1.8T while in the case of the traditional magnet structure, the maximum magnetic density of the back iron is about 2.2T. Obviously, using Halbach magnet structure can effectively reduce the degree of magnetic saturation of the back iron as well as the magnetic loss.

2. In the case of the Halbach magnet structure the range of the magnetic density peak is 0.80T-0.85T while in the case of the traditional magnet structure the range of the magnetic density peak is 0.72T-0.76T.Thus,using Halbach magnetic pole structure can effectively improve the air gap density.

3. In the case of the Halbach magnet structure, the peak width of air gap magnetic density is about 41mm which is account for 95% of the width of the magnetic pole while in the case of the traditional magnet structure, the peak width of air gap magnetic density is about 26mm which is account for 95% of the width of the magnetic pole. Thus, the magnetic flux leakage of the main magnetic circuit can be reduced effectively by using the Halbach magnet structure.

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