The application of the permanent magnet bearings in the Vertical Axis Wind Turbine

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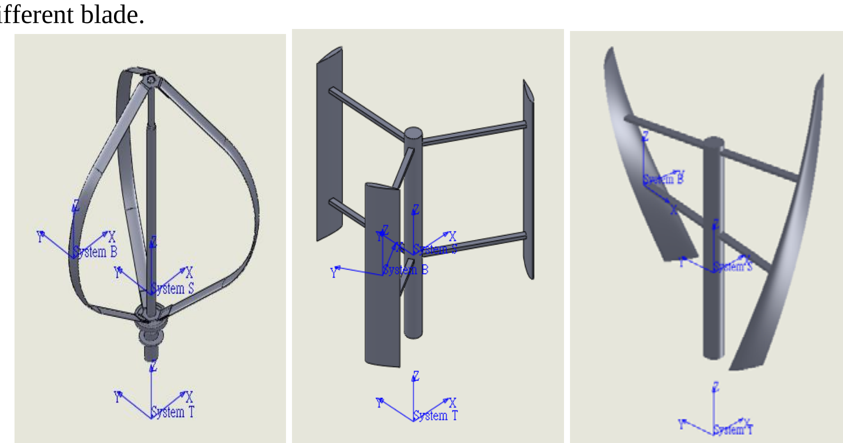
Abstract

This paper introduces the structural design of the permanent magnetic bearing for axial suspension on wind turbine, including the supporting schemes and the selection of the permanent magnetic material. The calculation of the bearing capacity and the stiffness are given, and suitable stiffness can reduce the vibration caused by the changes of the wind load. Experimental comparation of wind turbines starting torque supported by the magnetic bearing and by the mechanical bearing was carried out. And it is proved that the magnetic bearing can significantly reduce the starting torque of the wind turbine, thereby the starting wind velocity can be also reduced. Meanwhile, the wind turbine can work for a long time without lubrication, which affords lower maintenance costs, reduces the noise and greatly raises the efficiency.

1 Vertical axis wind turbine

Vertical axis wind turbine (VAWT), as an important form of the utilization of wind energy, has many advantages, such as low cost, simple-structured blades, convenient installation and maintenance and the ability to utilize wind from all directions. And now it is being increasingly widely used. Fig.1 shows several types of the VAWT with different blade.



（a）Darrieus VAWT （b）HVAWT （c）Rotate HVAWT

Figure 1: Several types of the VAWT with different blade

All the VAWTs shown above can utilize wind from all directions without the need of a steering mechanism when rotating in the horizontal plane. Meantime VAWT also has the advatages of less occupied area and quieter. The blade of the VAWT is ever-changing and the imagination can be fully developed, the turbine can be designed just like a work of art when the technology and the exquisite shapes are united.

Magnetic bearing technology can be applied to the wind power generation, which is particularly suitable for the VAWT. The VAWT using the permanent magnetic bearing is introduced in this paper, whose weight is almost

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entirely supported by the permanent magnetic bearing. The application of the magnetic levitation technology to the wind turbine reduces the frictional factor in axial axis near to zero when the turbine is rotating. Besides the traditional advantages of the VAWT, the VAWT with magnetic bearing has other advantages, such as low starting wind velocity and high wind power utilization factor.

2 The structure design of the permanent magnetic axial bearing in the wind turbine

Regardless of the horizontal axis wind generator or vertical axis, the higher of starting wind speed, the lower of the wind utilization, it's also not suitable for appling below the three type of wind zone. The average annual of wind speed in three type of wind zone is 3m/s, while it is the same with the starting speed of small wind generator, so the year generating hours are very small.

In vertical axis wind generator, the weight of blade,wheel arm and wheel hub take up a large proportion of the total weight of the wind generator, which are borne by the coaxial generator. Mechanical bearings will undertake great axial pressure, and have great friction force, increase the starting torque, the corresponding starting wind speed is larger, which cannot breeze power generation. When appling permanent magnetic levitation wind turbine structural design, the axial of wind turbine is supported by the permanent magnetic thrust balance bearing, the friction coefficient is very small when the wind wheel spins.

Axial permanent magnetic bearing can be manufactured to the structure as shown in Fig.2, this system merely controls the axial DOF of the permanent magnetic ring, while radial is unstable. In Figure 2, (a) and (b) is repulsive type permanent magnetic bearing, (c) and (d) is suction type permanent magnetic bearing.

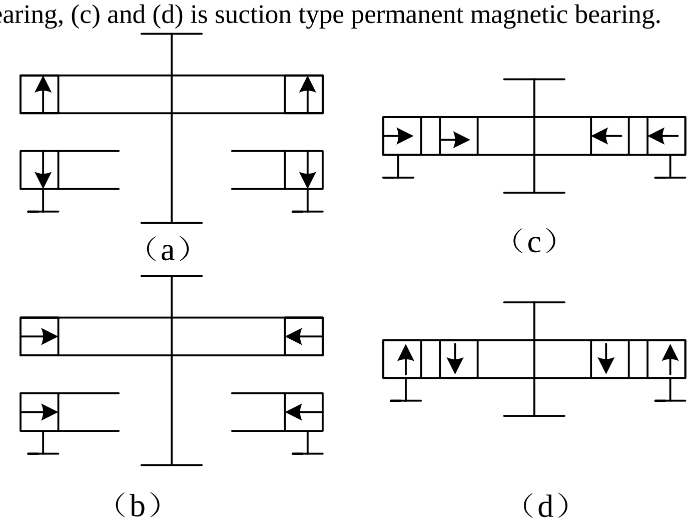


Figure 2: The basic structure of axial permanent magnetic bearing

Generally, permanet magnetic bearings are consist of multiple permanet magnetic ring which arranged in certain polarity, it use the repulsive force which generated by the dynamic and static permanent magnetic rings to support the shaft. When the shaft suffer unbalance force in the bearing control direction, the air gap between the dynamic magnetic ring and the static magnetic ring will be changed, the repulsive force in the minimum air gap is larger than the maximum air gap, and it will change the displacement of shaft control direction to the equilibrum state.According to Earnshaw theorem, magnetic bearing system which consist of only permanent magnetic cannot achieve a stable equilibrium on all DOF. Therefore, for the permanent magnetic bearing system, it should add an external force(such as the electromagnetic force, mechanical force, gas power, etc.) at least in one direction to realize system stability, so a mixed support of the permanent magnetic bearing and mechanical bearing are used, the bearing structure of wind turbine generator is shown in figure 3, the lower is generator, the upper is wind turbine, the structure of axial magnetic bearing is divided into the upper magnet and lower magnet. Radial magnetic bearing can be mechanical bearings, these components are constituted a hybrid bearing system. The axial is always in the suspended state when the wind turbine is in trotary motion.

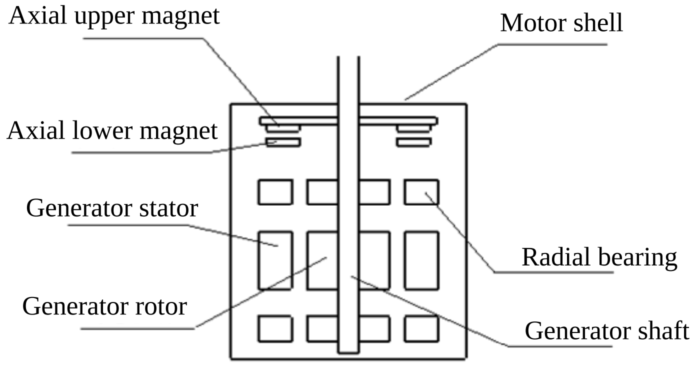
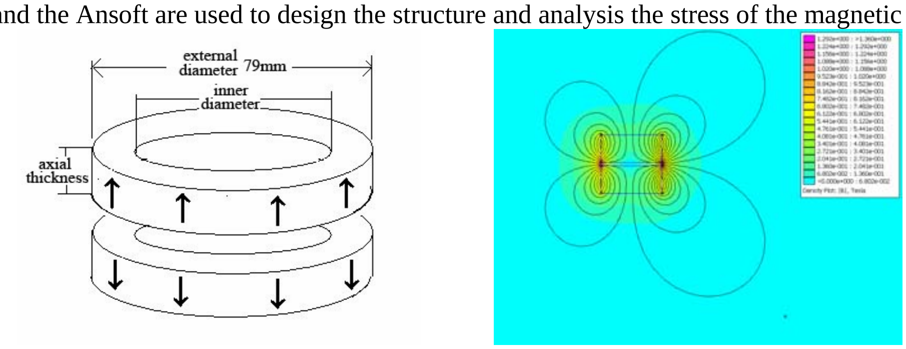


Figure 3: Structral diagram of wind turbine system

High energy product Nd-Fe-B magnetic material are selected, the bearing capacity of the magnetic bearing is related to the size and shape of the upper and lower magnet. The bearing capacity of ring shape permanent magnet is related to its internal diameter and thickness, and the characteristics of magnetic ring with different shapes and sizes can be calculated by magnetic circuit method or magnetic field analysis method.

3 The structure design of the permanent magnetic axial bearing in the wind turbine

The calculation of the bearing capacity and the stiffness of the wind load first, the permanent magnetic bearing axial finite element model is established using the magnetic field analysis method. We can choose the low cost with high fuction pernent magnent such as the N38, N40 or the N42. Ansoft finite element analysis software such as Femm and the Ansoft are used to design the structure and analysis the stress of the magnetic bearing.



(a)Axial permanent magnetic bearing model (b) the spatial distribution of the magnetic field

Figure4: Axial permanent magnetic bearing model and the spatial distribution of the magnetic field

Analysis and calculations are made for magnets with different thickness and different air gap size and the and for different diameter. Table 1 shows the data for 1 mm air gap (in appendix A).

Figure 5 shows the relationship between the bearing capacity and the thickness. We can study that, the bearing capacity rising rapidly with the increaes of the axial thickness when the inner diameter chosen as 60mm. the bearing capacity get little increase and become saturated f-inally with the increase of the thickness when the inner diameter ch-osen as 75mm.

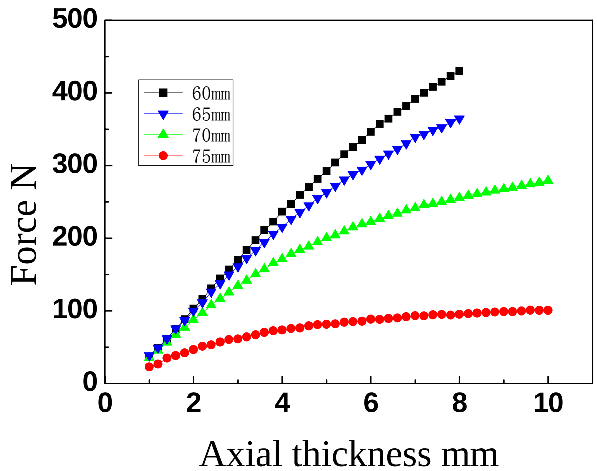


Figure 5: Relation between the bearing capacity and the thickness when the suspended air gap is 1mm.

Figure 6 shows the relation between the pernent magnatic bearing capacity and the axial thickness when the suspended air gap is 1.5 mm. In this case,65mm diameter and 4.4mm magnetic ring is the most appropriate since its size 13.93m³, is smallest compared with those of 60mm and 70mm with the same bearing capacity. Fig.6 shows the relation when is gap is 1.5mm, it is similar with that of 1mm, but the slope is smaller. It shows that the rate of the change became smaller along the increase of the thickness when the gap rises.

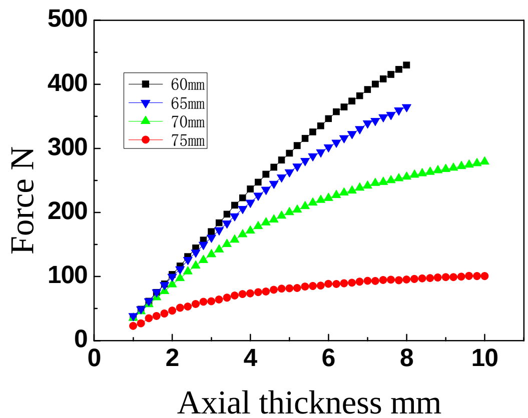


Figure 5: Relation between the bearing capacity and the thickness when the suspended air gap is 1mm

Stiffness calculation formula is as follows:

$$K_z = -\frac{dF_z}{dz} \tag{1}$$

It can be obtained that the magnetic bearing stiffness is 133.4N/mm.

4 experiment and conclusion

4.1 Starting torque comparation with and without magnetic bearing

Starting torque of wind generator is tested with and without magnetic bearing, which are shown in Table 2.

	Starting force（g）	Average torque（N.m)
Five blade, without suspension	300-350	0.3575
Five blade, with suspension	270-305	0.3155
Four blade, without suspension	230-270	0.275
Four blade, with suspension	200-230	0.243

Table 2: Starting torque of wind generator test with and without magnetic bearing

As shown in Table 2, The starting force and average torque are reduced with magnetic bearing,, this will no doubt reduce the starting wind speed.

4.2 wind turbine speed comparation with and without magnetic bearing

Figure 7 shows the experimental result with and without magnetic bearing of wind turbine in the same wind speed.

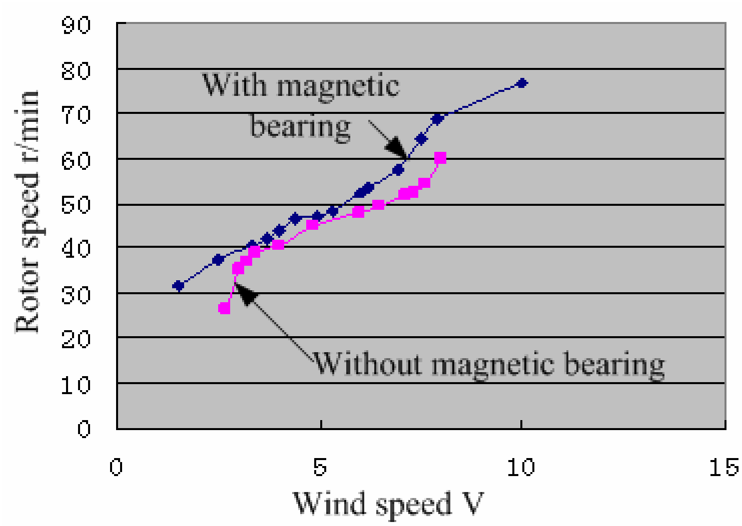


Figure 7: Rotor speed comparation with and without magnetic bearing

As shown in Figure 7, in the same wind speed, wind generator with magnetic bearing has higher rotor speed, this means that the annual generation hour of wind turbine with magnetic bearing will increase, and in the same wind speed, the generation efficiency of wind generator with magnetic bearing is higher than that without magnetic bearing.

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A Appendix A

Table 1 The relation between bearing capacity and the size of the magnetic ring when the gap is 1mm.

inner diameter60mm			inner diameter65mm			inner diameter70mm			inner diameter75mm		
Axial thickness mm	Magnet volume cm3	bearing capacity N	Axial thickness mm	Magnet volume cm3	Bearing capacity N	Axial thickness mm	Magnet volume cm3	bearing capacity N	Axial thickness mm	Magnet Volume cm3	Bearing capacity N
1	4.15	36.25	1	3.17	38.57	1	2.11	35.47	1	0.97	22.71
1.2	4.98	48.99	1.2	3.80	49.11	1.2	2.53	45.60	1.2	1.16	26.77
1.4	5.81	61.21	1.4	4.43	61.83	1.4	2.95	56.37	1.4	1.35	34.86
1.6	6.64	75.09	1.6	5.07	75.68	1.6	3.37	67.36	1.6	1.55	38.20
1.8	7.47	88.15	1.8	5.70	86.79	1.8	3.79	76.98	1.8	1.74	42.17
2	8.30	102.98	2	6.33	100.06	2	4.21	87.55	2	1.94	46.58
2.2	9.13	116.42	2.2	6.97	111.50	2.2	4.63	97.19	2.2	2.13	51.08
2.4	9.96	130.94	2.4	7.60	126.20	2.4	5.06	107.89	2.4	2.32	52.98
2.6	10.79	144.42	2.6	8.23	137.61	2.6	5.48	116.82	2.6	2.52	56.94
2.8	11.62	156.65	2.8	8.87	149.71	2.8	5.90	125.68	2.8	2.71	60.32
3	12.45	169.80	3	9.50	161.09	3	6.32	134.51	3	2.90	61.29
3.2	13.28	183.61	3.2	10.13	172.44	3.2	6.74	141.97	3.2	3.10	64.08
3.4	14.10	197.10	3.4	10.77	183.26	3.4	7.16	150.45	3.4	3.29	66.83
3.6	14.93	211.20	3.6	11.40	194.39	3.6	7.58	157.31	3.6	3.48	70.22
3.8	15.76	222.76	3.8	12.03	205.77	3.8	8.00	165.64	3.8	3.68	72.44
4	16.59	236.56	4	12.67	215.41	4	8.43	171.39	4	3.87	73.57
4.2	17.42	247.07	4.2	13.30	226.43	4.2	8.85	178.30	4.2	4.06	75.68
4.4	18.25	259.56	4.4	13.93	235.76	4.4	9.27	184.29	4.4	4.26	76.48
4.6	19.08	270.53	4.6	14.57	245.00	4.6	9.69	188.76	4.6	4.45	79.17
4.8	19.91	281.76	4.8	15.20	255.00	4.8	10.11	194.57	4.8	4.64	80.90
5	20.74	292.33	5	15.83	262.87	5	10.53	200.40	5	4.84	81.55