Structure design of a new-style moving blade adjusted axial fan

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Abstract: The moving blade adjusted axial fan is used in the icing wind tunnel, controlling of rotation rate and adjustment of angle of blades in the static state to achieve the test Mach (*Ma*) number in the kinds of condition. The axial fan should have the following advantages: wide range of speed regulation, stable performance, high efficiency and low operation cost. During the design process, lots of techniques were applied,e.g. dual bearing support and carbon fiber reinforced epoxy blade were adopted to solve the stiffness problems of hub caused large amount of blades and high radio of hub diameter to fan diameter,angle of blades was adjusted synchronously and fixed by a unique blade regulated mechanism together with the connecting device and the supporting device,and so on. The moving blade adjusted axial fan has been operating stably for a long term. The result showed that the performance of the fan satisfied all requirements.

Introduction

The icing wind tunnel has ability of the icing test（between 0 km to 7km）and the low Reynolds number test in high altitude（between 7km to 20km）[1]. In the process of design,we have troubles in meeting operational environment and some especial requirement of the fan, such as wide operating temperature range（from -30˚C to 30˚C）, high humidity (between 70％RH to 100％RH) , negative atmosphere (0.05×10^5Pa), and angle of blade difference in the kinds of condition, have to run a large number of work in the field of different conceptual comparison and finite element analysis (FEA).

Axial fan survey

This fan depends on a forced air cooling AC motor which is controlled by frequency transformer to realize Ma number adjustment for the test section, adjusted mechanism is controlled to realize angle of blades adjustment, is shown on Fig.1.

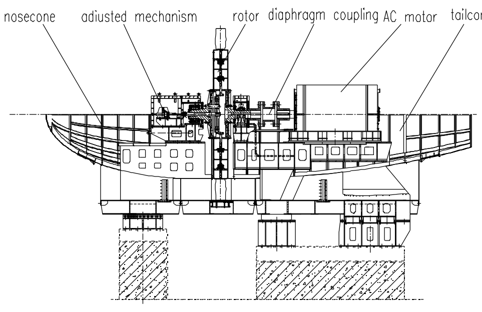

Fig.1 Fan structure

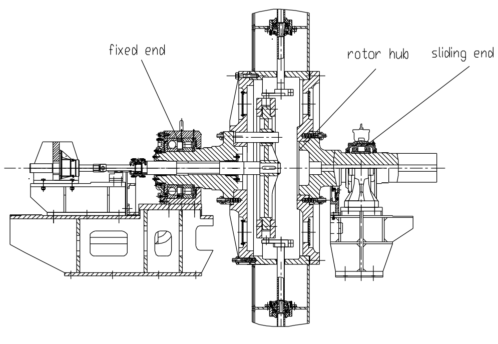

Fig.2 Rotor hub support

The max output power of motor is 6000kW. Speed range of the rotor is from 40rpm to 600rpm.

The blade employs the RAF-6 series blade section, angle adjusted range is from -20°to 20° [2].

Axial fan general Conceptual design

Angle of blade adjusted. According to the icing pilot wind tunnel test results, angle of blade adjusted range is 30°, so it must be adjusted for fan of the icing wind tunnel in order to achieve great efficiency in different working conditions and requisite test *Ma* number .Generally, manual mode is beyond accomplish because of lower efficiency, larger adjusted range, atrocious environmental condition and repeatedly adjustment. For this mode, blade and rotor hub is connected together through flange with a large-holes, it need such a circle to loosing connector, revolving blade to requisite angle, and fixing connector when angle of blades needed to be adjusted. Further say, the frequently-used adjusted mechanism is adopted hydraulic system in domestic and abroad for the moving blade adjusted axial fan in which rotor hub is single-point supported (the rotor assembly overhung on the motor shaft), but it is ill-suited because of more difficult maintenance in vacuum environment and different support method which will be explained in following article. Integrated above, electric adjusted mechanism is adopted.

Conceptual ascertain of rotor hub support. There are two methods of single-point support and dual support (the rotor assembly supported at both ends bearing block) to support rotor hub. For the moving blade adjusted axial fan, rotor hub support usually employs single-point support method because it is advantageous to design of the blade adjusted mechanism, but this moving blade adjusted axial fan does not employ on account of factors described below. The first, hub rigidity is weak. On the one hand, because blade support equipment can but arranged outboard ring of the rotor hub for blade's quantity, outboard ring would have enough thickness to overcome centrifugal load, conversely would lead to whole hub load increasing, rigidity reducing. On the other hand, promotion of hub rigidity is finite because of limited outline and assembly space. The optimize result explained that the rotor hub has large deformation. The Second, hub stress is high with the result that choosing material of fine welding function is difficult. The end, mode natural frequencies keep away from hub disc frequencies effectually on the base of dual support, which is shown on Fig.2.

Choose of blade material. The carbon fiber material has applied widely to aerospace domain because it has higher specific strength and specific stress than common metallic materials, but less used to the axial fan in domestic because of cost for control in the past. With material cost has been reducing and the system has been establishing and improving gradually, which include material system, techniques system of melting prepared, autoclave, and resin transfer process(RTM) forming [3,4], the carbon fiber material will certainly help to blade design and manufacturing. Overall consideration, blade material employs carbon fiber reinforcements epoxy resin composites.

Main components design

Blade adjusted mechanism design. In the process of design, many problems are encountered, include:

a. How to connect between adjusted mechanism and blade for dual support rotor hub?

b. How to only achieve linear movement for a linear motion shaft (push rod) of electric adjusted mechanism and fix position for blade when rotor is in work statement?

Take steps include:

a. The electric adjusted mechanism is comprised of the actuator cylinder with one lifting jack connected to an electric gear motor, motion decoupling device separating rotational motion of rotor hub and linear motion of actuator cylinder, push plate subassembly and its supporting device, which is shown on Fig.3. The push plate subassembly may glide along its supporting device which includes three shafts fixed on rotor hub and self-lubricated bearings. The slider located into spout of the push plate subassembly moves along glide plane, and pushes fork fixed blade variable moment shaft end to rotate so as to the purpose of adjusting angle of blade.

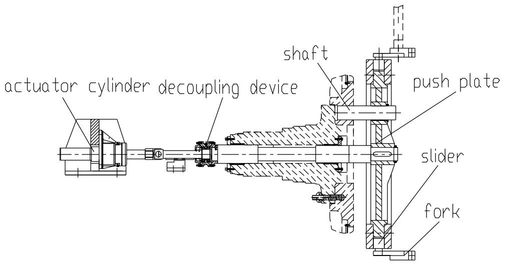

Fig.3 Moving blade adjusted mechanism

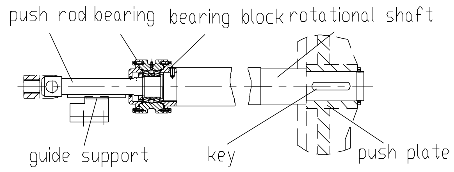

Fig.4 Decoupling device

b. The motion decoupling device includes bearing, bearing block, a linear motion shaft connected to the bearing inner ring by interference fit, a rotational motion shaft connected to the bearing outer ring by clearance fit, et al[5], which is shown on Fig.4. The bearing block is synchronous motion with rotor hub.

c. The push plate subassembly includes push plate, panels, 27(twenty seven) sliders, et al. The push plate connected to a rotational motion shaft supported on three shafts of circumferential uniform distribution which are fixed on rotor hub. The slider is made of steel block overlaying copper alloy and bonding graphite staff in its hole.

d. Self-lubricated bearings are chosen in mating parts which have relative moving.

Blade connected and supported device design. The connection between blade and its adjusted mechanism does not adopted structural form of whole bearing carrier similarly the TLT, HOWDEN, AP moving blade adjusted axial fan, need to be redesigned because of limited outline and assembly space.

a. The centrifugal load and aerodynamic load acted on the blade transmit to different position of hub which is shown on Fig.5 respectively by spherical roller bearings and self-lubricated bearings.

b. For the variable moment shaft, one end is connected with a blade handle by a rigid coupling, another end is connected with a slider by fork.

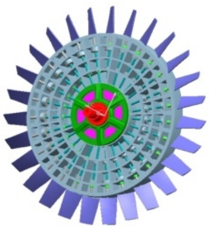

Fig.5 Fan rotor hub

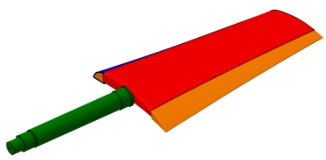

Fig.6 Blade structure（no shell）

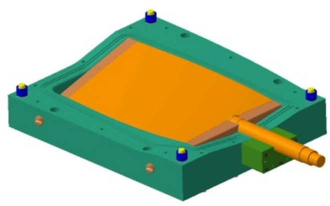

Fig.7 Blade outer skin in female mould

Composite blade structure design. Blade composes of a metallic blade handle and composite blade, which consists of supporting beam, blade leading edge reinforcement, core and shell [6], see Fig.6.

In order to enhance their joint strength, high-performance carbon fiber prepared are lain along blade root axial, bypassed its joint position and solidified forming with foam core.

Shell consist of two layer, out-layer is used to meet blade profile dimension precision and has some of loading capacity; in-layer is used to provided sufficient bending and torsion stiffness.

The blade leading edge is reinforced to prevent its damage from exotic due to the high blade velocity, to increase part torsion stiffness of the blade at same time.

The autoclave solidification technology is adopted to control blade profile of leading edge, supporting beam and in-layer shell. The resin transfer molding (RTM) process was used to ensure the blade profile geometrical tolerance, see Fig.7.

Testing

35CrMo forging impact work test. Besides material performances comply with the JB4726 [7] relevant technology standards, an extra mechanical property analysis is added on the basis of the HG20584 [8] standards, which impact work averages of three samples are no less than 40J [9, 10] under -30˚C condition.

Composite blade performances test. The experimental verification is a important work in the process of complete blade manufacturing, because the difference of the resin content will cause the material density fluctuation; the difference of layer direction will bring about different strength, stiffness and eigen frequency of structure; the confirmation of the resin and fiber mechanical properties and the FE mathematical model simple in FEA will may cause some of the differences between computing results and testing results.

The testing content involves stiffness checking test in normal atmospheric temperature and low temperature (-30˚C) condition, bonding strength test and dissection test [6]. The stiffness checking results showed that displacement deviation is within 5% and 2.5% in the flap direction and in the lag direction respectively. The bonding strength test is check joint between metallic material and composite material in the blade root if not damaged at four times the maximum centrifugal load. In the process of testing, no abnormal noise appears in the joint, no hamstring injury appears in the loading position. In the subsequent, loading position and given sections do not appear phenomena of layered, degumming, microscopic crack, and tearing.

Eigen frequency measurement. Through twelve accelerations to measure blades response in different positions by striking different directions of normal, tangential and bias normal, Results showed that calculation results are consistent with measured results, deviation is within 3%, see Tab.1, that each frequency of blade avoids hub disc frequency which is shown on Tab.2, each mode characteristic does not coincide. So it avoids effectively the occurrence of the resonance phenomenon.

Table 1 Computational and test modal

modal number	frequency Hz(static)	frequency Hz（measure	frequency Hz(dynamic)	mode characteristic
1	89.9	86	92.5	first flap
2	125.8	128	132.6	first lag
3	320.6		292.8	first torsion

Table 2 Hub disc natural frequency

Modal number	frequency Hz	mode
1	21.18	first bend
2	49.78	first stretch
3	54.04	second stretch
4	97.53	first torsion
5	156.6	Second bend
6	213.06	second torsion

Balance testing. The test is step by step implemented, the first is that static unbalance valve of rotor hub located on balancing table is less than 30g.m, the second is that shaft vibration velocity of the rotor system is less than 4.6m/s in the condition of different rotational speed with assembly site.

Conclusion

a. The moving blade adjusted axial fan has been operating stably for a long term. The result showed that the performance of the fan satisfied all requirements.

b. There will has more options to design of the moving blade adjusted axial fan due to successful use of a newly blade adjusted mechanism.

c. It will wide material chosen space for blade in the field of the axial fan, centrifugal fan, even compression engine that a kind of carbon fiber reinforcements epoxy resin blade with independent intellectual property right is successful development.

References

[1] Qiang Peng. Icing wind tunnel aerodynamic design conditions. EJ-4-2008056, CARDC. 2008. (in Chinese)

[2] Zhilong Huang. Icing wind tunnel fan aerodynamic design conditions. EJ-4-2008150, CARDC, 2008. (in Chinese)

[3] Shanyi Du. Advanced composite material and aeronautics and astronautics. Composite Material. 2007, 24(1):1-12. (in Chinese)

[4] Yongqing Sheng. Development of resin matrix composite technology. Journal of XIAN Aerospace Technology Vocation Technical School. 2008, 26(1): 12-15. (in Chinese)

[5] Zebin Yu. Icing wind tunnel fan section rotor system construction design. EJ-4-2011030, CARDC, 2011. (in Chinese)

[6] Zebin Yu, Zhengcong Liu, Shuang Leng, et al. Structure design and manufacturing of the composite blade for the icing wind tunnel. Journal of Applied Mechanics and Materials. Vols.397-400(2013) p621-624.

[7] National Committee of Pressure Vessel Standard. JB4726. Carbon and Low-alloy Steel Forgings for Pressure Vessels. 2000. (in Chinese)

[8] National Chemical Engineering Construction Standard Editing Center. HG20584. Technical

Requirements for Fabrication of Steel Chemical Vessels.1999. (in Chinese)

[9] Weilian Sun, Yuying Yang. 35CrMo steel microstructure and properties. Metal Heat Processing. 2005.30(11):79-82. (in Chinese)

[10] Guangkui Zhu. The improved of 35CrMo steel Quenching and Tempering heat treatment. Liaoning University of Science and Technology. 2008.31(2):129-131. (in Chinese)