Research on Application of Shutter Flow Regulating Valve in Aerodynamic Performance Test of Fan

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Abstract: Taking DN700 shutter flow regulating valve as research object，the CFD model of vehicle cooling fan aerodynamic performance test system is established by using Gambit and Fluent software. Through analysis of pressure field and velocity field in duct, the application of shutter flow regulating valve in aerodynamic performance test of fan and influence of different types of fans on performance test were discussed. The results indicated that shutter flow regulating valves can be substituted for traditional sticking paper in aerodynamic performance tests of fan. These make it possible to automatically control air flow of operating state point and sample for performance test of fan. These researches provide a reference for the automation of aerodynamic performance test for vehicle fans.

1 INTRODUCTION

C-type experimental set-up specified in GB/T 1236-2000(2001) or ISO 5801:2007 often used in aerodynamic performance tests of cooling fan in vehicle. During the process of these tests, people usually stick a paste on the loading mesh of test pipeline to load the inlet manifold of fan to adjust flow quantity. But there are some shortcomings: selection of test mode point is not controlled due to stochastic of paste; there is high risk of test person because of exposure to test environment of rotating part in manual stick method. They can be overcome by using shutter flow regulating valve to adjust flow quantity, and sampling control test mode point to realize automatic aerodynamic performance test of fan.

Shutter Flow regulating valve often used in wind-tunnel tests, when the diameter of pipeline is small, it can't be used in fan test. Because if use shutter flow regulating valves to adjust flow quantity in small-diameter pipeline, it will guide downstream air flow and result in unevenness flow. And the test will be invalid if can't get rid of it after the air flow passing through the rectifying gate.

Familiar shutter flow regulating valves can be divided into united opening type and divided opening type, see figure 1. When the valves change, all of the blades of united opening valves will rotate in the same direction and the blades maintain parallel to each other, but the rotation of adjacent blades of divided opening type is opposite. In this paper, the shutter flow regulating valves used in pipeline of fan test is numerically simulated（Li Jianfeng, 2006; Chang Zezhou, 2009; Liu Song, 2009）by Fluent, include united opening type and divided opening type, and the influence on airflow is analyzed and contracted to confirm whether it can be used in aerodynamic performance tests of fan or not.

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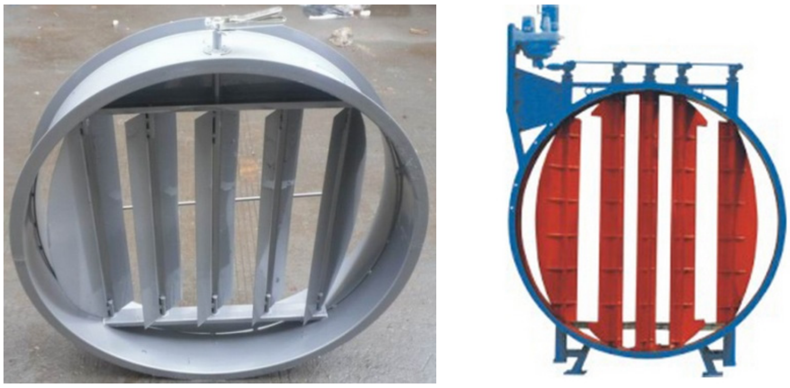


(a) united opening type (b) divided opening type

Fig. 1: shutter flow regulating valve

2 VALVE AND DUCT MODELLING

2.1 Geometry model

Object is a pipeline that inner diameter is 700mm, calculated model is shown in Figure 2.

Calculate area is divided into inlet section and impeller area. Inlet section is flow field area between pipeline inlet and fan inlet, include inlet flatness tube segment, shutter flow regulating valve, fairing screen and pipeline public segment, the pressure hole on pipe wall is ignored during the modeling. The single axial fan used have no guide vane, parameter as follows: rim diameter 320mm, outer diameter 690mm, width 200mm, 8 vans uniformly distribute around, rating rev is 1750r/min.

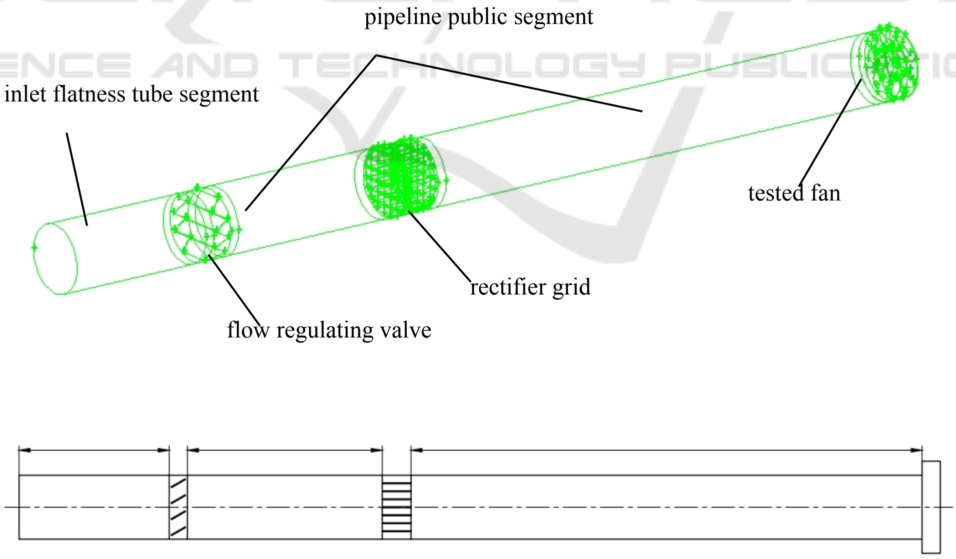


Fig. 2: calculate area model

There are 4 vanes in a shutter flow regulating valve, which is 175mm high and 4mm thickness.

To research the influence of united opening type and divided opening type valves in different opening on test system flow field, 9 calculated model of different opening are established in 10°, 20°, 30°, 40°,50°,60°,70°,80°,90°.

2.2 Mesh model

Impeller area: the edge of tetrahedron mesh is 8mm which compartmentalize the area, and the dimensional function is further encrypted for the area of blade tip clearance. The number of grid cells is about 1.2 million.

Inlet section: because the flow field near the flow regulating valve and rectifier grid is rather complex, it is necessary to divide the flow field with dense mesh in order to ensure calculation higher accuracy. The tetrahedron mesh and the hexahedron mesh with the edge of 10 mm are used to divide the meshes respectively. Due to its regular shape and low mesh quality, cylindrical pipes are divided into hexahedron grids with long edges in order to save computational resources. The total number of grids in the whole inlet section is about 3 million.

3 CALCULATION PROCESS AND RESULTS

3.1 Calculation method and boundary condition

The air is regarded as incompressible fluid, there is no heat exchange in the flow, and the energy conservation equation is not taken into account. The gas is steady flow, the constant calculation is adopted, and the influence of gravity is ignored. The turbulent model adopts a standard k - ε model , the near wall is applied with a standard wall function , and the pressure velocity is coupled with SIMPLE algorithm , momentum equation , turbulent kinetic energy and turbulent dissipation phase . The convergence criterion is defined as the residual less than 1×10^{-4} for all monitoring items.

The inlet boundary condition is set as the pressure inlet , and the inlet total pressure is defined to be zero relative to the atmospheric pressure ; the outlet boundary condition is set to the pressure outlet , and the outlet static pressure is defined to be zero relative to the atmospheric pressure ; and the solid wall adopts the non - slip boundary condition .

3.2 Analysis of CFD flow Field affected by Valve to Air duct

3.2.1 Flux characteristics of Valve

The flux percentage of the fan varies with the opening of the valve blade as shown in Fig. 3. It can be seen that the flux characteristics of the united opening valve are close to that of the fast opening valve and the flux is bigger when the opening of the valve is small. When the blade opening is 70 °, the fan flux rate is close to the maximum value, and then the flux rate just vary a little while the opening degree increases,.

The variation of flux characteristics of divided opening valve showed different rules, with the increase of opening, the rate of change with flux of the fan increased first and then decreased. When the opening is less than 30 °, fan flow changes slowly with the increase of opening; when the blade opening between 30 °and 70 °, flux change from the maximum of 20% increases to 90% rapidly with the increase of opening fan, the rate of change with flow is bigger than united opening valve; when the opening increasing further, the rate of change becomes very small, the flow characteristics now is similar to that of united opening valve. At the same time it can be seen that the flow of divided opening type is always less than that of united opening type at same opening of valve.

The flow regulating valve is installed in the pipeline, hoping to get a linear working characteristic, but the two kinds of valves do not have a good linearity. The working range of the united valve is 0 ° -70 °, and the working range of the divided valve is 20 °-70 °.

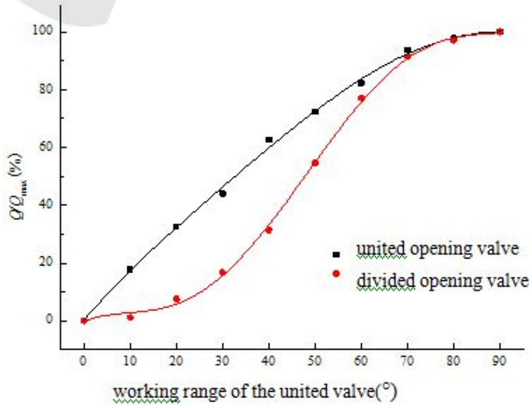


Fig.3simulated characteristic curve of shutter flow regulating valves

The full - pressure efficiency of the fan is shown in Fig. 4. It can be found that the two curves are basically the same shape, especially in the small flow area and the large flow area , this two curves are same, which indicate the two valves can be used to obtain the more accurate curve of the fan performance .

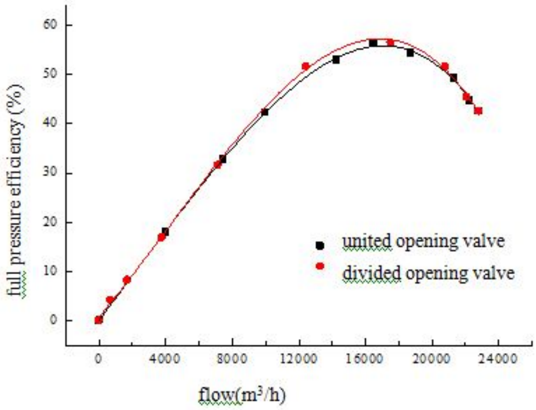
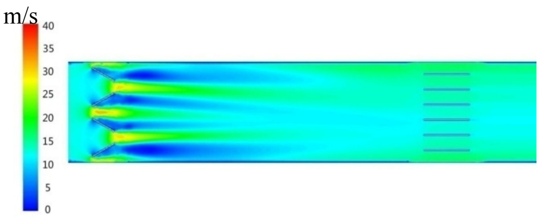


Fig. 4 simulated characteristic curve of fan

The calculated flow rate of rating point of the fan is18000m^3/h, and the corresponding valve opening is approximately 60 °, so the further analysis is carried out with the valve blade opening of 60°.

3.2.2 Speed distribution

(a) united opening type



(b) divided opening type

Fig.5 pipeline velocity chart when valve opening is 60°

When the valve opening is 60 °, the shutter flow regulating valve and the flow velocity near the gate distribution are shown in Figure 5.From Figure 5 (a)we can see: when united valve blade along the diversion effect of the gas flow through the valve strands of the same direction deflection occurs, and converge on top of the pipeline, resulting in velocity of upper air significantly greater than the downside. The average speed of upper airflow is 20.5m/s in the pipe, and the velocity of lower pipe flow is less than 5m/s, so two blocks form a clear boundary.

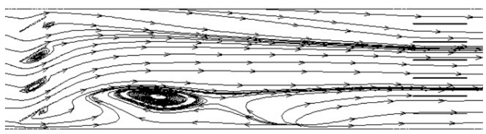
At the same opening, effect of united valve on the flow direction of deflection is much weaker. From figure 5 (b) we can see: through the valve gap between the blades the airflow forma high-speed jet, these high speed jet flow along the axial direction and converge at the head of rectifying grids. The velocity distribution of downstream flow field is uniform and the average speed is about 12m/s.

3.2.3 Streamline and turbulent kinetic energy

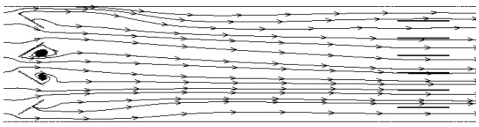
Figure 6 and Figure 7 show the kinetic energy distribution of streamline and turbulent near the flow regulating valve and the rectifier grid. It can be seen that due to the strong shear action of high-speed jet and low-speed fluid at leeward side, fluid eddies at the leeward side of leaves, resulting in a significant increase in the turbulent kinetic energy.

For the united opening valve, the three vortex areas above is intensity but range over a small field, the bottom vortex area is weak but range over a wide field. The mainstream converged by three jets shear each other with low-speed fluid lower in the pipeline, to form a larger vortex, resulting in disordered flow between the valve and rectification grid. The nephogram shows that the turbulent kinetic energy lower in the pipeline is 15 times more than the lower, at the same time we can see: the turbulent kinetic energy decreased significantly after passing through rectifying grid, the turbulent kinetic energy downstream in rectifying grid is within 5m^2/s^2, indicating the rectifying grid can eliminate secondary flow and combing the flow field effectively.

The vortex area of divided opening valve is concentrated on the rear part of the two central blades, and the incidence is small. When the valve downstream pass through about 1.5D, the turbulent kinetic energy of the flow field decreases rapidly, and the velocity distribution is very uniform at the grid.

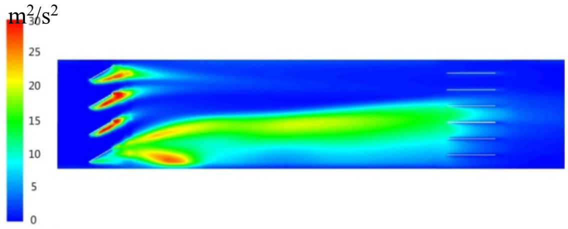


(a) united opening type

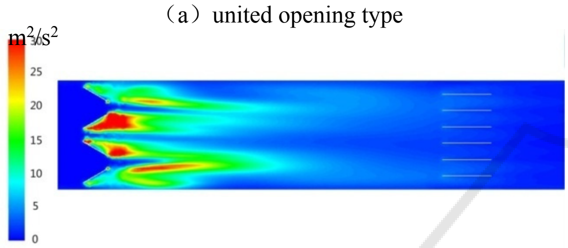


(b) divided opening type

Fig.6 streamline of pipeline at 60 ° opening



（a）united opening type



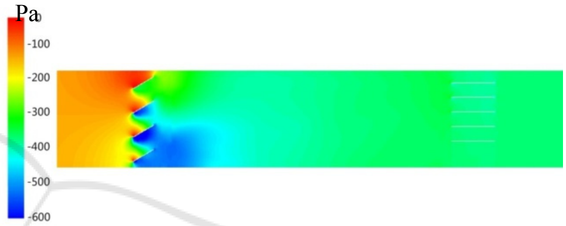
（b）divided opening type

Fig.7 turbulent kinetic energy nephogram of pipeline at 60 ° opening

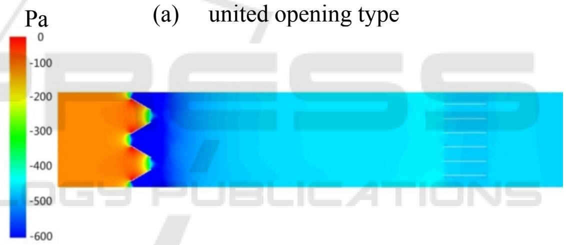
3.2.4 Pressure distribution

Figure 8 shows the hydrostatic distribution of shutter flow regulating valve and the flow field near the rectifying grid. The valve blade blocks the fluid resulting in the increased static pressure of blade windward side, static pressure energy translate into dynamic pressure which forming a low pressure area due to the vortex exits in leeward side of vanes. For the united opening valve low pressure area at the bottom range over a wide field, in the downstream within about 1D of the valve the pressure gradient of pipe is obvious, and then the flow pressure distribution tends to be uniform. The static pressure distribution of divided opening valve is symmetrical about the central axis, the low pressure area range over a wide field and values small, after the low pressure area the static pressure increase gradually, static pressure uniformly distributed at the rectifier grid. It can be seen that the distribution of low pressure and vortex area is consistent.

Figure 9 and figure 10 are dynamic pressure and static pressure nephogram of static pressure measuring section using two kinds of valves. It can be seen that due to the downstream flow field of rectifying grids is flat, no matter which kind of valve we use, static pressure distribution of static pressure measurement section are uniform. The main influence of the valve is the dynamic pressure, when using the united opening valve, the dynamic pressure measured on section is far greater than the lower side, and this is consistent with the velocity distribution in the pipe; when using divided opening valve, the dynamic pressure distribution on the section is equality. When using C type test device for fan aerodynamic performance test, dynamic pressure of fan is calculated by flow, gas density and cross-sectional area rather than measurement directly, so the uneven distribution does not affect the dynamic pressure in fan test, but this will directly affect the accuracy of static measurement.



(a) united opening type



（b）divided opening type

Fig.8 static pressure nephogram of pipeline at 60 ° opening

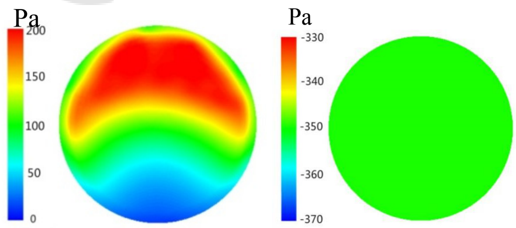


Fig.9 dynamic pressure and static pressure distribution of static pressure measurement section (with united opening flow regulating valve)

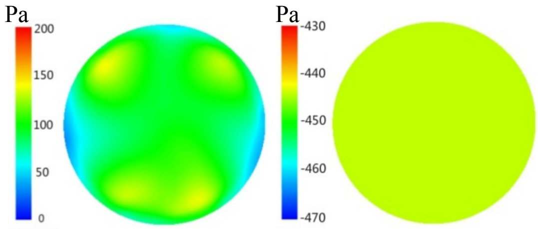


Fig.10 dynamic pressure and static pressure distribution of static pressure measurement section(with divided opening flow regulating valve)

4 CONCLUSIONS

By simulating the flow characteristics of valves and the internal flow field of united opening valve and divided opening shutter flow regulating valves in different opening degrees, the following conclusions can be drawn:

1)Both valves can elicit accurate performance curve of fan. It basically meets the requirement of using C type test device specified in GB/T 1236-2000 or ISO 5801: 2007 in aerodynamic performance test of fans.

2) The flow range of the fan is allowed from 8 000 m^3 / h to 20 000 m^3 / h, and the opening range of the flow regulating valve is 30 °-70 °. Within this range, the flow characteristics of the two valves is nearly linearity, which meets the need of sampling control of test operating conditions.

3) The deflecting effect of the united opening valve on the airflow direction is obvious, which leads to a big velocity gradient in the downstream flow field, and a large scale vortex will be formed in the downstream of the valve due to the strong shear action of both sides of the airflow. So the flow loss is caused and the influence range of vortex is increasing with the decrease of opening. The velocity distribution of downstream flow field in divided opening valve is relatively uniform. There is a vortex region with little influence only in the rear of the blade. Therefore, in the point of reducing energy loss, the divided opening valve is superior.

4)The static pressure distributions of the static pressure measurement section of the two valves are uniform, but the dynamic pressure distribution is quite different. When the united opening valves work, the aerodynamic pressure above the cross section is much larger than that on the lower side, which is consistent with the velocity distribution in the pipeline. The dynamic pressure distribution on the cross section is uniform when adopting the divided opening valve. The uniformity of the dynamic pressure distribution will affect the accuracy of the static pressure measurement directly. Therefore, divided opening valve is superior considered measurement accuracy.

In summary, when using C type test device specified in GB/T 1236-2000 or ISO 5801: 2007 in fan aerodynamic performance tests, the inlet duct can be loaded by the divided opening shutter flow regulating valve instead of the manual sticker method in order to realize the sampling control of mode point and test automation.

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