Analysis of fluid-solid coupling vibration characteristics of probe based on ANSYS Workbench

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Abstract

The research object is probe. The five-hole probe can be used as a flow measurement tool for various angles in wind tunnel test. The inlet flow rate condition is set. The finite element co-simulation is performed by ANSYS Workbench to study the fluid-solid coupling effect. The effect on the probe was further analyzed by modal vibration. The simulation results show that the maximum equivalent stress of the probe under the pressure of the flow field in the air occurs on the windward side of the support rod, but less than the yield stress of the material, and the total deformation trend gradually decreases from the bottom of the probe to the top of the support rod. The maximum deformation occurs at the windward surface of the bottom of the probe. The existing dimensions fully meet the requirements of use. In order to improve the efficiency, the structure and size can be improved. The natural frequency of the structure is higher and the stiffness is better. Also consider avoiding the natural frequency of the structure to prevent structural damage.

Keywords

Probe, fluid-structure coupling, deformation, vibration.

1. Introduction

For space aerodynamic measurement, it is necessary to measure the velocity field in three-dimensional space, including the speed and direction. At present, many new sophisticated instruments and methods have emerged, such as hot wire measurement, laser measurement and high-speed image analysis with microcomputer[1]. In terms of economy and ease of use, etc., it is convenient to obtain the flow velocity, direction, total pressure and static pressure of air, liquid, etc. by using probes such as two-hole, five-hole, seven-hole, etc., and can also be used for measuring wind. Various large-angle flow measurements in the hole test, such as the measurement of the airflow angle and speed of the rotating machine, have a wide range of applications, and therefore have extremely high requirements for probe design and performance analysis. In this paper, the unidirectional fluid-solid coupling method is used. Firstly, the SolidWorks modeling software is used to build the three-dimensional model of the probe, and the model is poured into the Fluen software. The boundary conditions are set to obtain the distribution of the pressure and flow velocity of the external flow field of the probe, and the workbench is combined. The static mechanical analysis module considers the pressure field as the deformation and stress distribution of the applied load analysis probe to verify the rationality of the design. Finally, the modal analysis module in the workbench analyzes the modality during fluid-structure coupling to avoid structural resonance. Provide a basis for the destruction of the probe.

2. Probe structure design and working principle

Figure 1 is a three-dimensional diagram of the probe structure designed in this paper. It consists of two parts: the support rod and the probe. The head is spherical and consists of multiple pressure holes. The positive hole is open at the center of the cylinder, and the other pressure holes are evenly distributed along the ring. Wall thickness 0.5mm, speed measurement range: less than 0.9 Mach (<0.9Ma); angle measurement range: plus or minus 35 degrees; through the internal pipeline and pressure tap hole, the measurement accuracy is high. Figure 2 is a schematic diagram of the connection between the five-hole probe and the micromanometer. From the figure, it can be seen that the probe measures the pressure, flow rate and other variables of the fluid.

Fig.1 Five-hole probe shape

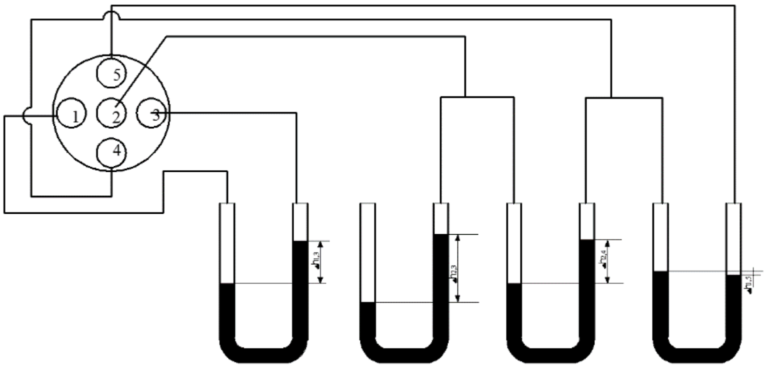

Fig.2 Five-hole probe and micro-pressurer connection

3. Model calculation method

3.1 Flow field numerical calculation method

The SIMPLE algorithm is used to realize the coupling between velocity and pressure, and the finite volume method is used to discretize the governing equation. The convection term uses a second-order upwind discrete, and the diffusion term uses a central difference format. The near-wall flow is described by the standard wall function method and solved using the standard k-turbulence model [2].

3.2 Statics finite element equation for strength calculation

$$k_u = F_s + F \ , \quad \sigma = DBu \qquad （1）$$

In the expression, k is the overall stiffness matrix, u represents the node displacement, F_s and F_t respectively represents the pressure generated by the fluid flow convection-solid interface and the inertial force caused by the rotation of the runner itself and gravity; σ is the structural stress; D is the elastic constant matrix of the structure; B matrix.

3.3 One-way fluid-solid coupling calculation method

The unidirectional fluid-solid coupling analysis solves the fluid control equation and the solid control equation in the same solver or different solvers in the set order, and exchanges the calculation results of the fluid domain and the solid domain through the fluid-solid interface to perform iterative calculation.

4. Model calculation process

4.1 Model overall calculation process

The Fluent solution model is started by Ansysworkbench. The specific flow chart is shown in Fig.3. Firstly, the external flow field pressure distribution and flow velocity distribution of the probe under air flow rate are calculated. Then, the static model is combined with the flow field model, and the pressure field data obtained by Fluent is applied as a load to the probe surface to obtain the flow field pair. The deformation and stress of the probe are affected. Finally, the results of fluid-solid coupling are added as pre-stress to the modal, and the natural frequency and modal distribution of the probe under fluid-solid coupling prestress are obtained.

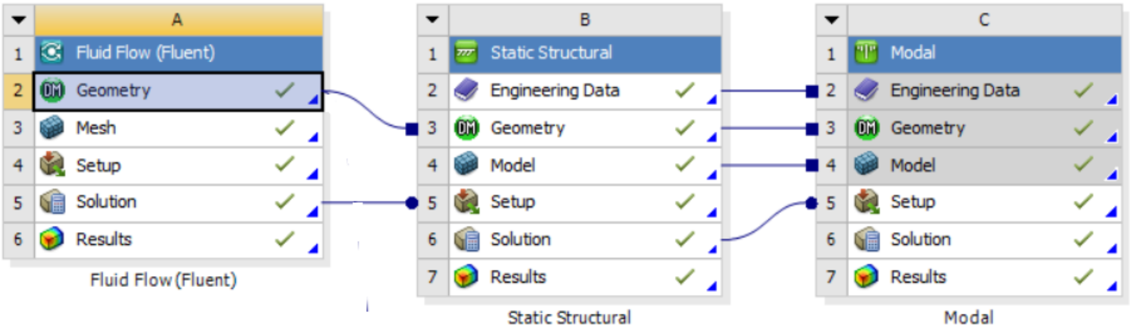

Fig.3 project process

4.2 Flow field analysis

4.2.1 Meshing and boundary condition setting

According to the selected model, the wind is treated as a viscous and incompressible fluid, and the probe surface is assumed to be free of slip and no penetration [3]. Since the probe is a symmetrical structure, in order to simplify the structure and reduce the calculation time, half of the model is selected as the analysis object. In this paper, the block technology is used to mesh the fans, which can minimize the number of meshes without affecting the accuracy of the solution. The model is discretized into 13020 nodes and 61432 grids (see Fig. 4).

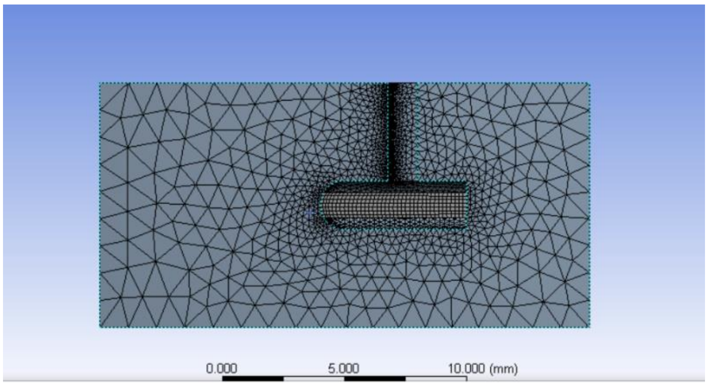

Fig.4 Flow field meshing

The solid domain is first suppressed before meshing. The purpose of designing the boundary condition is to improve the convergence speed, but the final converged flow field is independent of the initial conditions. The probe flow field model is composed of inlet, outlet and wall conditions, and symmetry is set. Constraints and fluid domains.

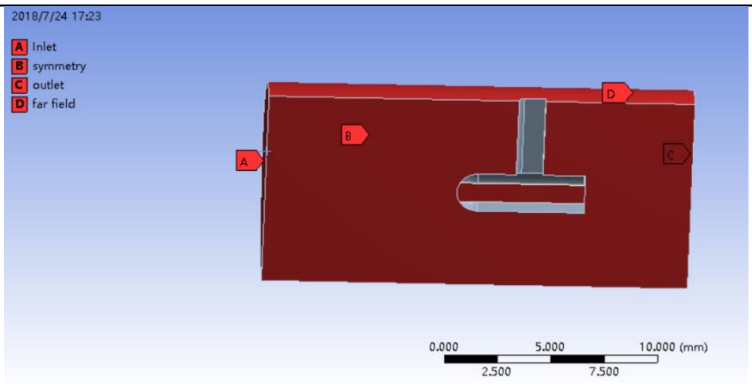

Fig.5 boundary condition settings

The probe model was set to the standard k-turbulence model. The inlet condition was set to the velocity (vecocity inlet), the velocity was 25 m/s, the turbulence intensity and turbulence rate were 5% and 0.01, respectively, and the outlet condition was set as the pressure outlet (Pressure Outlet).), set the outlet pressure to 0.

4.2.2 Solution Analysis

The numerical method used in this paper is SIMPLE algorithm. The number of iterations is 92 times. The convergence result is shown in Fig. 6. After viewing the results in CFD-POST processing software, the velocity vector diagram is shown in Figure 7, and the pressure cloud diagram is shown in Fig. 8.

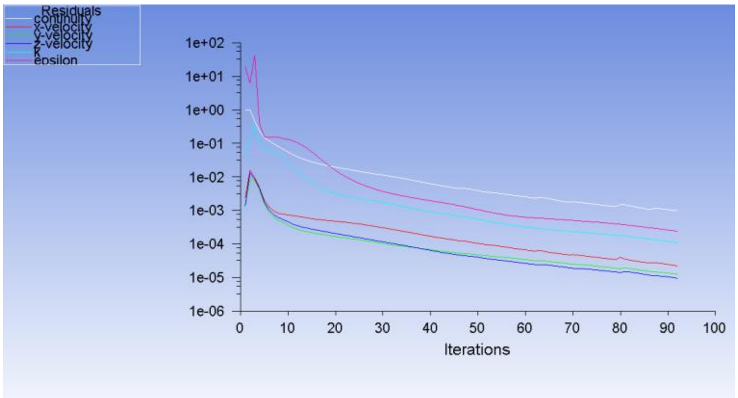

Fig.6 convergence curve

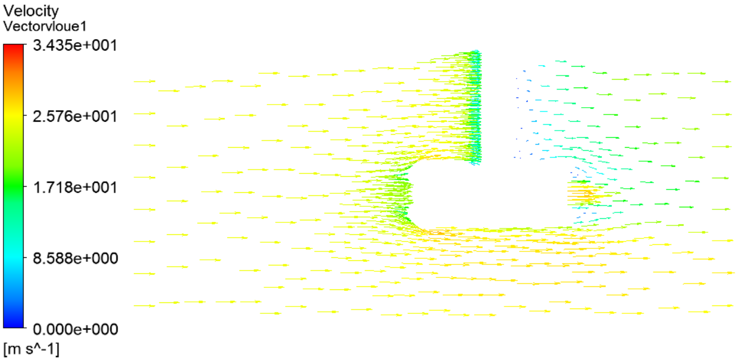

Fig.7 speed vector

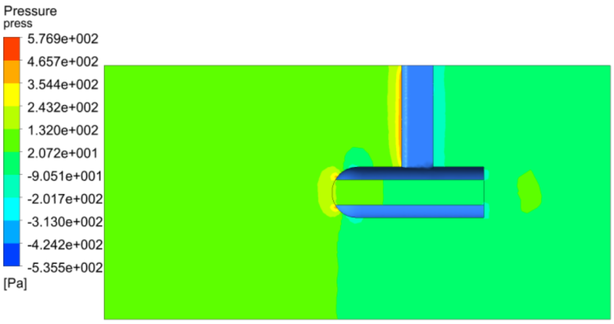

Fig.8 pressure cloud map

4.3 Static structure analysis

4.3.1 Meshing and boundary condition setting

When analyzing the structural stress and strain, the fluid portion is first suppressed, and only the solid region calculation is retained. When the probe model is meshed, local mesh encryption is used, and the rest is divided by silent mesh to generate 14591 nodes and 7983 cells. The mesh quality is mostly above 0.5, and the mesh analysis is better (see Fig. 9).

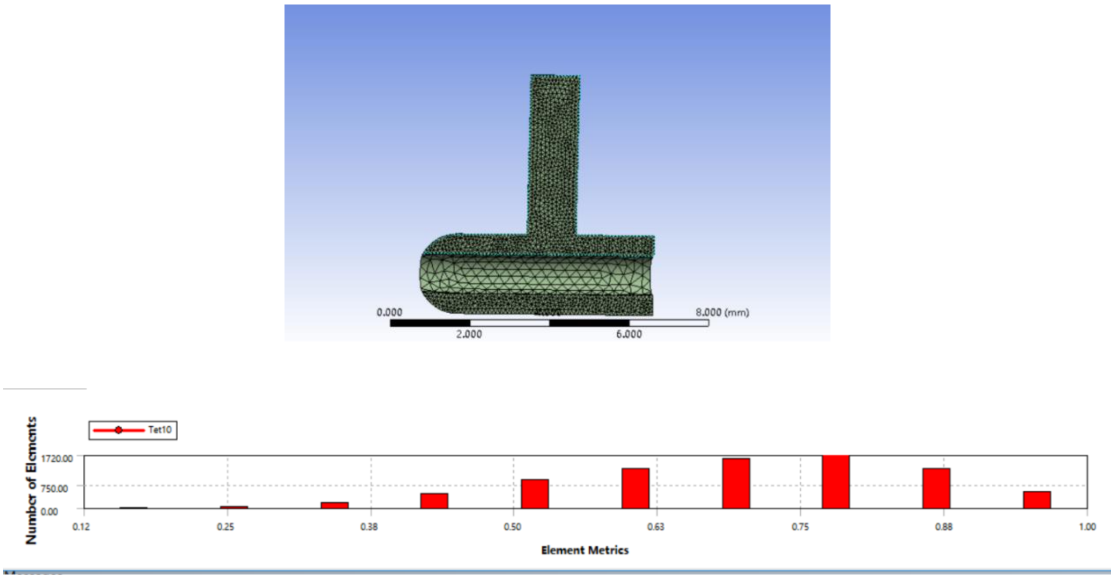

Fig.9 Structure field meshing and grid quality check

When the load is applied, the pressure of the flow field analysis is transferred to the static analysis and used for the probe surface (see Fig.10). After solving, the total deformation cloud of the probe is obtained (see Fig.11) and the equivalent stress cloud map (See Fig.12), the X-direction cloud map (see Fig.13) for the local stress cloud (see Fig.14).

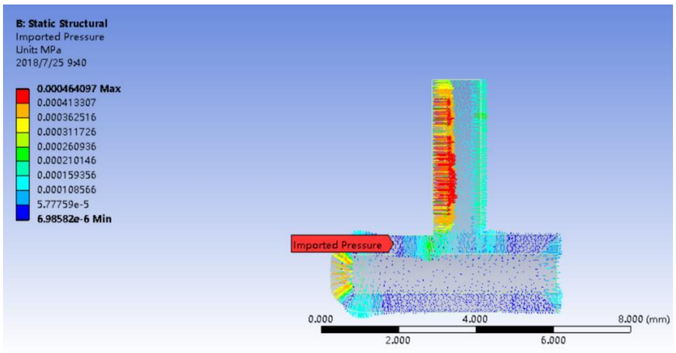

Fig.10 Introduction of the pressure field

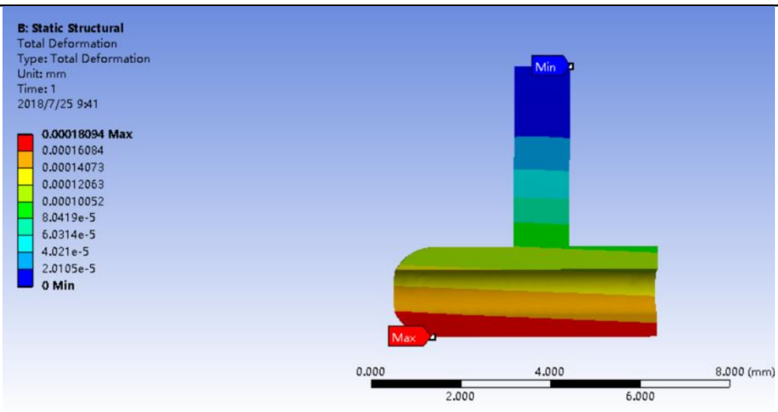

Fig.11 probe deformation cloud

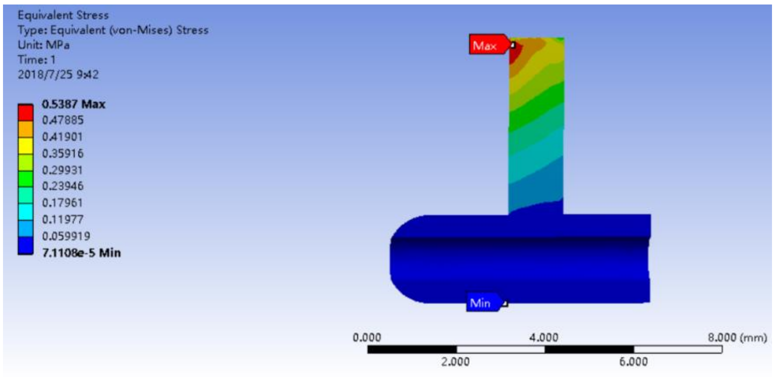

Fig.12 probe stress cloud

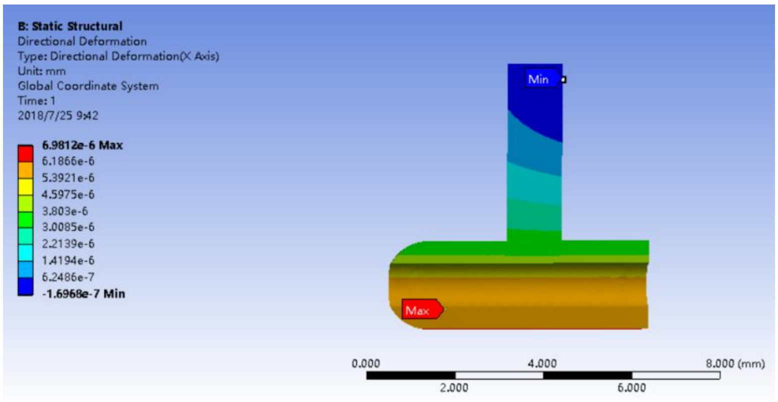

Fig.13 Probe X direction cloud image 4

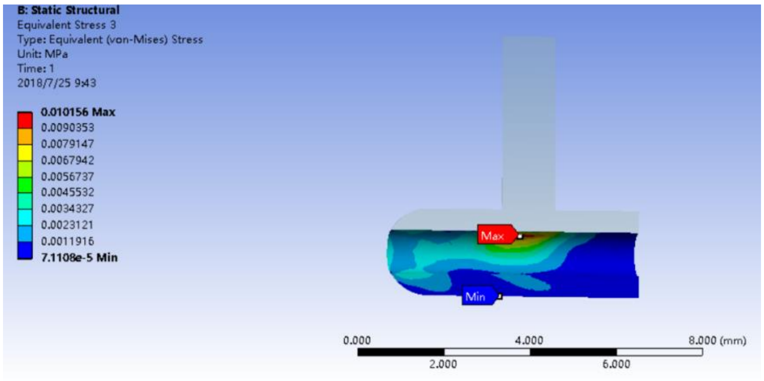

Fig.14 probe local stress cloud

4.3.2 Analysis of model results

The purpose of probe fluid-solid coupling analysis is as follows: one is strength check; the other is to provide basis for structural improvement based on the analysis results [3]. It can be seen from Fig. 12

that the equivalent stress of the probe under the pressure of the flow field in the air is 0.5387 MPa, which is the windward side of the support rod and less than the yield stress of the material. It can be seen from Fig. 13 that the total deformation tendency gradually decreases from the bottom of the probe to the top of the support rod, and the maximum deformation occurs at the windward surface of the bottom of the probe, and the deformation is 0.00018094 mm. The existing dimensions fully meet the requirements of use, and in order to improve efficiency, some improvements in structure and size can be made.

5. Modal analysis under fluid-solid coupling

A full constraint is applied to the upper surface of the support rod, and the constraint displacement is 0. The first six modes of the probe are calculated, and the natural frequencies are as shown in Table 1.

Table 1 Natural frequency of the probe

Mode	Frequency/(Hz)
1	1860.1
2	4421
3	8176.7
4	19563
5	37648
6	73689

It can be seen from Table 1 that the natural frequency of the structure is high, the fluid-solid coupling has a great influence on the natural frequency of the system, the rigidity of the structure is good, and the damage is not easy to occur. Redesign should avoid the natural frequency of the structure, prevent resonance and damage the structure.

6. Conclusion

According to the above results, since the probe is a symmetrical structure, 1/2 of the model can be selected for fluid-structure interaction analysis; the probe is used in the measurement of various large angles of the flow in the wind tunnel test. The important role, through the fluid-solid coupling and modal analysis of the probe, provides a certain reference for the structural design of the probe.

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