Loads Analysis of Flanges of a Transonic and Supersonic Wind Tunnel Wide Angle Diffuser

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Abstract: *Compared with general circular flanges, flanges on conical shells have different configurations. In the Chinese national code GB150, however, there are no related contents about flange design of this kind of type. So, it needs to study loads of flanges of this kind of type. This paper takes the flange connection of a wide angle diffuser in a transonic and supersonic wind tunnel as the background, according to the principles of flange design in Chinese national code GB150, combining the characteristics of flanges of a wide angle diffuser, the loads of flanges have been analyzed, and the equations of loads and their locations have been presented.*

Key words: transonic and supersonic wind tunnel; wide angle diffuser; flange; loads analysis

1 Introduction

Pressure vessels are widely applied in industrial sectors. The operating conditions and media of most pressure vessels often have a high temperature, high pressure, flammable, corrosive and poisoning characteristics, and they are bound up with human security [1].

The wind tunnel is the most basic testing equipment for aerodynamics research and aircraft development. It is an aerodynamics test equipment in a piping system designed according to certain requirements using a power device to drive airflow which can be controlled according to the principles of relativity and similarity of the movement [2]. Therefore, a wind tunnel belongs to a pressure structure in operation and should be designed to meet the relevant requirements of pressure vessels.

As an important part of pressure vessels, the cross-section of flanges is usually circular [3~5]; there are some cross-sections of flanges designed to be of non-circular shape, such as a rectangle, oval, oblong, etc [6]. But the internal cross-section dimensions of shells connected to these flanges are generally consistent in the direction of flange thickness. However, the design of a wind tunnel needs to set flanges on the diffuser, we will be encountered the situation that the shell connected to the flange is a cone. To the author´s best knowledge, no attempt has been reported on the loads analysis of flanges on conical shells.

The calculation method of flanges for pressure vessels, applied most extensively in the world, is Waters method, such as ASME of the United States, CODAP of France, JIS of Japan, GB150 of P. R. China [7]. In this paper, based on the Chinese national code GB150, the loads and their locations of flanges of a wide angle diffuser in transonic and supersonic wind tunnel will be analyzed.

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2 Wide angle diffuser

With the development of a transonic and supersonic wind tunnel, comparing with the aerodynamics design of the stilling chamber of a low-speed wind tunnel, there are some changes in the design requirements and aerodynamics design items of the stilling chamber of a transonic and supersonic wind tunnel. With the large contraction ratio used, the requirements proposed that it should try best to reduce the size (volume) of the stilling chamber's upstream piping; it needs to set the wide angle diffuser (WAD) at the entrance of stilling chamber. According to the statistical data, the open angle of the WAD is between 30° to 90°, and it is usually more appropriate to select 45° [2].

The schematic profile of the WAD is shown in Figure 1.

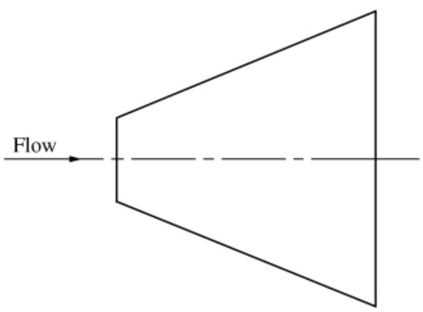

Figure 1 Schematic profile of the WAD

The front-end of the WAD connects with air piping (its internal diameter is equal to that of the entrance of the WAD), and the back-end of the WAD connects with the stilling chamber (its internal diameter is equal to that of the exit of the WAD).

3 Flanges of a WAD

Due to the process requirements, the design in order to facilitate installation, inspection and maintenance of equipment, flanges are set on the WAD. As the weld between flange and shell is full-welded, therefore the flange is looked on as an integral one and its schematic profile is shown in Figure 2.

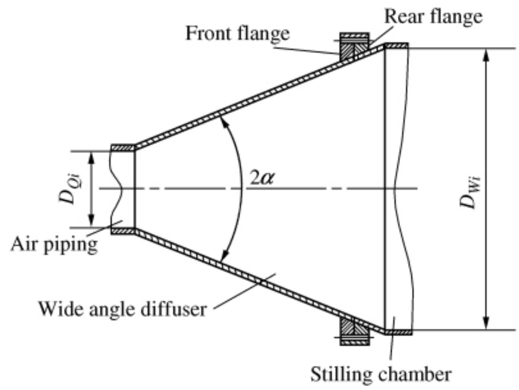

Figure 2 Schematic profile of the WAD with flanges

where α is the semi-opening angle of the WAD, D_{Qi} is the internal diameter of air piping with corrosion allowance deducted, namely the internal diameter of the entrance of the WAD, D_{Wi} is the internal diameter of the stilling chamber with corrosion allowance deducted, namely the internal diameter of the exit of the WAD.

4 Flange calculation

The main formulae and symbol definitions of flange calculation can refer to section 7 of Reference [3]. This paper describes only the contents where there are differences with Reference [3] in calculation.

4.1 Front flange calculation

Loads' locations of the front flange are shown in Figure 3.

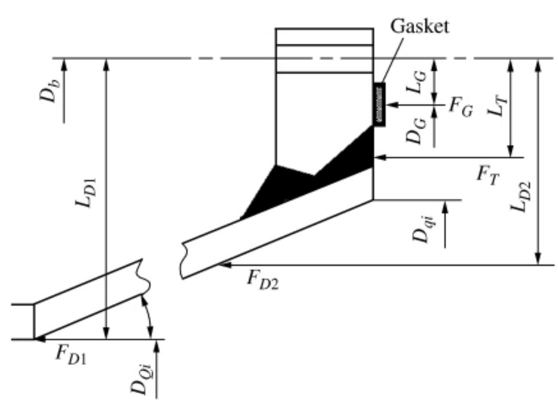

Figure 3 Schematic profile of loads' locations of the front flange

The axial force F_{D1}, acting on the internal diameter cross-section of the entrance of the WAD is caused by internal pressure as follows:

$$F_{D1} = 0.785 D_{Qi}^2 p_c \tag{1}$$

Where p_c is the calculation pressure.

The axial force F_{D2}, acting on the internal surface of the shell of the WAD, is caused by internal pressure as follows:

$$F_{D2} = 0.785 (D_{qi}^2 - D_{Qi}^2) p_c \tag{2}$$

Where D_{qi} is the internal diameter of the front flange´s face with corrosion allowance deducted.

The difference F_T between the total axial force F and F_{D1}, F_{D2}, is caused by internal pressure as follows:

$$F_T = F - F_{D1} - F_{D2} \tag{3}$$

The radial distance L_{D1} from the location of F_{D1} to the bolt center is as follows:

$$L_{D1} = \frac{D_b - D_{Qi}}{2} \tag{4}$$

Where D_b is the diameter of the bolt center circle.

The radial distance L_{D2} from the location of F_{D2} to the bolt center is as follows:

$$L_{D2} = \frac{D_b - 0.5 (D_{qi} + D_{Qi})}{2} \tag{5}$$

The radial distance L_T from the location of F_T to the bolt center is as follows:

$$L_T = \frac{D_b - 0.5 (D_{qi} + D_G)}{2} \tag{6}$$

Where D_G is the diameter of the center circle where the compression force of the gasket acts.

The torque of the front flange is as follows:

$$M_p = F_{D1} L_{D1} + F_{D2} L_{D2} + F_T L_T + F_G L_G \tag{7}$$

Where F_G is the compression force of the gasket and L_G is the radial distance from the location of F_G to the bolt center.

4.2 Rear flange calculation

Loads´ locations of the rear flange are shown in Figure 4.

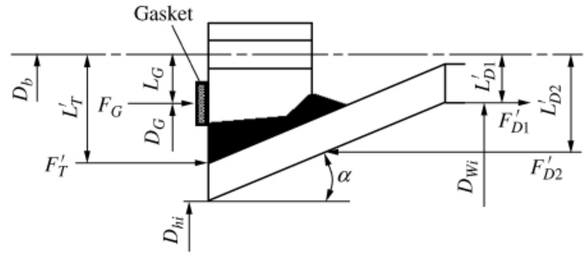

Figure 4 Schematic profile of loads´ locations of the rear flange

The axial force F'_{D1}, acting on the internal diameter cross-section of the exit of the WAD, is caused by internal pressure as follows:

$$F'_{D1} = 0.785 D_{Wi}^2 p_c \tag{8}$$

The axial force F'_{D2}, acting on the internal surface of the shell of the WAD, is caused by internal pressure as follows:

$$F'_{D2} = 0.785 (D_{Wi}^2 - D_{hi}^2) p_c \tag{9}$$

Where $D_{hi} = D_{qi} + 2\delta_g \tan\alpha$, where D_{hi} is the internal diameter of the rear flange´s face with corrosion allowance deducted and δ_g is the thickness of the gasket.

The difference F'_T between the total axial force F and $F'_{D1} - F'_{D2}$, is caused by internal pressure as follows:

$$F'_T = F - (F'_{D1} - F'_{D2}) \tag{10}$$

The radial distance L'_{D1} from the location of F'_{D1} to the bolt center is as follows:

$$L'_{D1} = \frac{D_b - D_{Wi}}{2} \tag{11}$$

The radial distance L'_{D2} from the location of F'_{D2} to the bolt center is as follows:

$$L'_{D2} = \frac{D_b - 0.5 (D_{hi} + D_{Wi})}{2} \tag{12}$$

The radial distance L'_T from the location of F'_T to the bolt center is as follows:

$$L'_T = \frac{D_b - 0.5 (D_{hi} + D_G)}{2} \tag{13}$$

The torque of the rear flange is as follows:

$$M_p = F'_{D1} L'_{D1} - F'_{D2} L'_{D2} + F'_T L'_T + F_G L_G \tag{14}$$

5 Conclusions

With the analysis of loads and their locations of flanges of the WAD in a transonic and supersonic wind tunnel, it can be concluded in the following:

1) The structural dimensions, axial forces caused by internal pressure and their locations, and torques of the front flange and rear flange are varied.

2) Loads and their locations of flanges are relevant to the location where flanges locate on the WAD, the internal diameter of the entrance of the WAD, the internal diameter of the exit of the WAD and the opening angle of the WAD.

3) As it is close to the entrance of the WAD, the locations of F'_{D1} and F'_{D2} may exceed the bolt center circle, thus the algebraic signs of relevant items in Equation (14) should be changed.

4) Equations(1) ~ (14) can be applied to the calculations of flanges on similar conical shells bearing internal pressure.

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