The Influence of the Angle of the Reverse Shoulder on the Performance of Premium Casing Connection

Long Hao, Meng Mu*

Department of Mechanical Engineering, Zhonghuan Information College Tianjin University of Technology, Tianjin 300380, China.

*Corresponding author: mumeng1988@tjut.edu.cn

Abstract. The premium casing connection is composed of three parts: the main sealing structure, the reverse shoulder structure and the thread. The angle $\theta$ of the reverse shoulder has an important influence on the strength and sealing performance of the premium casing connection. Based on the idea of factor rotation method, the influence of parameter $\theta$ on the maximum contact pressure of the main sealing surface of the premium casing connection, the contact pressure of the shoulder surface and the internal stress of the connection is studied through finite element simulation experiments. The results show that the greater the angle of the reverse shoulder, the better the sealing performance of the connection, but the worse the anti-torsion ability of the connection.

1. Introduction

With the continuous development of oil and gas resources in the direction of ultra-deep wells, horizontal wells and unconventional gas wells, the connection strength and sealing performance of the casing API standard joints have been difficult to meet the technical requirements of oilfield use. The premium casing connection is an important direction for the development of oil well pipe production technology in the future. The research and development of premium casing connection products in Europe and the United States began in the 1940s. At present, the annual output of European and American steel pipe manufacturers accounts for more than 85% of the world's total. There are about a hundred types of premium casing connection produced, and more than ten types are more typical and widely used [1-3]. China started late in the research and development of premium casing connection, and a large number of high-end premium connection products still need to be imported [4].

The premium casing connection is composed of three parts: the main sealing structure, the shoulder structure and the threaded part. Usually, the main sealing structure and the reverse shoulder structure of the premium casing connection are jointly characterized by multiple parameters, and each parameter has a different level of change. As a result, there are many combinations of parameters. At present, the research methods of premium casing connection mainly include finite element simulation and full-scale test [5-6]. If these structural parameters are optimized through full-scale tests, it will produce high costs and difficult workloads. According to the idea of factor rotation method, this paper adopts finite element simulation method to study the influence of structural parameters on the strength and sealing performance of premium casing connection. It not only provides an important theoretical basis for the optimization of structural parameters, but also reduces the workload and test cost.
2. Structure of premium casing connection
The main sealing structure of the premium casing connection has many forms. This article takes the premium casing connection of the spherical/cylindrical main sealing structure as an example, as shown in Figure 1. The premium casing connection with spherical/cylindrical main sealing structure is composed of three parts: spherical/cylindrical main sealing structure, reverse shoulder structure and thread. For the main sealing structure, the parameters that can characterize the sealing performance are mainly the spherical curvature radius $r$ and the interference $\delta$. For the reverse shoulder structure, the reverse angle $\theta$ is its main structural parameter. The three quantities of spherical curvature radius $r$, interference $\delta$ and reverse angle $\theta$ have a great influence on the performance of premium casing connection. However, due to the limitation of the length of the article, this article only introduces the influence of the reverse angle $\theta$ parameter on the performance of premium casing connection.

![Figure 1. Spherical/cylindrical main sealing structure for premium casing connection.](image)

3. Simulation test plan
This article designs the simulation test plan according to the basic idea of the factor rotation method. The factor rotation method is also called the isolated factor method or the single factor analysis method. It is a non-comprehensive test method to solve the multi-factor test problem. The basic idea is that in each experiment, only the level of one factor is changed, and the levels of other factors remain fixed. Then find out the influence of each factor on the index one by one, find the optimal level of each factor, and then combine these optimal levels into the optimal plan of the experiment. This method reduces the number of tests and improves test efficiency.

In this paper, the shoulder reverse angle $\theta$ is used as the analysis factor, and the factor $\theta$ is set to 6 levels of 0°, 5°, 10°, 15°, 20° and 25°. The calculation model used is 139.7 mm (5 1/2 inches), 9.17 mm wall thickness, N80 steel grade casing. It is assumed that the maximum tensile load is 850 kN and the internal pressure is 60 MPa.

In the simulation test, "two as much as possible" is used as the test index, that is, the internal stress of the connection should be as small as possible, and it is best to control the maximum stress within the initial yield limit of the material, which is beneficial to repeated use. The contact pressure is as large as possible, which is in line with the sealing design principle of premium casing connection and can ensure a good sealing effect.

4. The influence law of parameter $\theta$ on connection performance
Assuming $r=18$ mm, $\delta=0.16$ mm, $r$ and $\delta$ remain unchanged, the simulation test results are shown in Figure 2. Figure 2 is a graph showing the change of the maximum contact pressure of the main sealing surface with the change of the angle $\theta$ of the reverse shoulder. Curves B and C are the calculated results of the connection only under the make-up torque and the connection under the combined load. Compound loads include make-up torque, tensile load and internal pressure load.

It can be seen from the curve in Figure 2 that only under the action of the make-up torque, as the reverse angle increases, the contact pressure on the main sealing surface increases significantly. Under the action of compound load, the curve changes smoothly, and the contact pressure on the main sealing surface only slightly increases.
Figure 2. The contact pressure of the main sealing surface varies with the angle $\theta$ of the reverse shoulder.

Comparing the two curves in the figure, when $\theta$ is larger, the maximum contact pressure of the main sealing surface under compound load is less than the maximum contact pressure under the action of only the make-up torque. When $\theta$ is smaller, the maximum contact pressure of the main sealing surface under compound load is greater than the maximum contact pressure under the action of only the make-up torque. It can be inferred from the curve trend that when the reverse angle is $16^\circ$~$17^\circ$, the maximum contact pressure of the main sealing surface is less affected by the load.

Figure 3. The contact pressure of the main sealing surface varies with the loading time.

The reason for the curve in Figure 2 is that the maximum pressure of the main sealing surface will decrease when the connection is subjected to a tensile load, and it will increase when subjected to an internal pressure load. Take the scheme with a reverse angle of $20^\circ$ as an example, as shown in Figure 3. Figure 3 is the curve of the maximum contact pressure of the main sealing surface with loading time. The loading time is 3 seconds. Only the make-up torque exists in the first second. After the first second,
the tensile load starts to be applied, and after the second second, the internal pressure load starts to be applied. The tensile load reduces the interference of the shoulder surface and the contact pressure of the shoulder surface decreases. Due to the reverse angle of the shoulder surface, the component force of the shoulder surface contact pressure in the radial direction will also be reduced, thereby affecting the radial contact pressure of the main sealing surface. Because the reduction under large angle is greater than the increase caused by internal pressure, and the reduction under small angle is less than the increase caused by internal pressure, so the maximum contact pressure of main sealing surface in the scheme with larger reverse angle under composite load is less than that under only make-up torque, and the scheme with small reverse angle has opposite results.

Figure 4. The curve of the contact pressure of the shoulder surface changing with $\theta$ under compound load.

The reverse angle $\theta$ is also an important factor affecting the contact pressure on the shoulder surface. Figure 4 shows the curve of the contact pressure on the shoulder surface of the connection as a function of the parameter $\theta$ under the action of compound load. The abscissa in the figure is the coordinate value of the grid node on the shoulder surface in the radial direction of the tube, and the ordinate is the contact pressure. It can be seen from Figure 4 that there is a peak in the contact pressure at both ends of the shoulder surface, which may be caused by the deformation of the shoulder surface after being loaded. In the middle of the shoulder surface, the contact pressure basically shows a downward trend. As the reverse angle $\theta$ increases, the average contact pressure of the shoulder surface will increase, that is, as the reverse angle increases, the auxiliary sealing effect of the shoulder is better. The study also found that when the connection only bears the make-up torque, the above-mentioned influence law of factor $\theta$ on the contact pressure of the shoulder surface also exists, but the effect is not obvious under the compound load, so it will not be listed here.

The shoulder reverse angle $\theta$ not only affects the contact pressure between the main sealing surface and the shoulder surface, but also has an important impact on the internal stress of the connection. Fig. 5, Fig. 6, Fig. 7, Fig. 8, Fig. 9, Fig. 10 show the Von-Mises stress diagram when the connection is under the make-up torque and $\theta$ is $0^\circ$, $5^\circ$, $10^\circ$, $15^\circ$, $20^\circ$ and $25^\circ$. It can be seen from the figure that the larger the reverse angle is, the larger the high stress area at the main seal and shoulder is, and the anti-torsion ability of the shoulder is decreasing.
Figure 5. Stress of the connection when $\theta=0^\circ$.

Figure 6. Stress of the connection when $\theta=5^\circ$. 

Figure 7. Stress of the connection when $\theta=10^\circ$.

Figure 8. Stress of the connection when $\theta=15^\circ$. 
Figure 9. Stress of the connection when $\theta=20^\circ$.

Figure 10. Stress of the connection when $\theta=25^\circ$. 
5. Conclusion
The shoulder reverse angle has an important influence on the performance of premium casing connection. The larger the shoulder reverse angle, the better the connection sealing performance, but the worse the anti-torsion ability. Considering various influences comprehensively, when the reverse angle is 15° or slightly greater than 15°, the connection not only has good sealing performance, but also maintains a certain torsion resistance.

References
[1] Anon. Premium joint for CRA oilfield tubulars. Ocean Industry, 1990, 25(3):125-130.
[2] Bethke M, Morey S, Schwind B. Improved integral joint casing connections can reduce well costs. Oil and Gas Journal, 1994, 45(5):30-35.
[3] Anon M. 2005 Tubing reference tables. World Oil, 2005, 259(1):29-35
[4] Li H L, Tian W, Kuang X R. Analysis and countermeasures of oil well pipe supply and demand situation. Steel Pipe, 2010, 39(1):1-2.
[5] Weiner P.D, True M.E. Unique device eliminates leaks in API connections. World Oil, 1969, 69(1):127-8, 132.
[6] Blose T.L Weiner P.D. Leak resistance analysis-- API 8-Round. IEEE Journal of Solid-State Circuits, 1979: 49-57.