The stress analysis of corrugated metal hose under bending conditions

Shichuang Gan, Hehui Wang*
School of Mechanical and Power Engineering, East China University of Science and Technology, Shanghai, China

*Corresponding author e-mail: 15102107225@163.com

Abstract. Corrugated metal hose, as an improved type of pipe, plays an important role in the development of modern industry. With the help of workbench, the numerical analysis of the bellows bending is studied. The bellows deform with the applied load, and the closer it is to the free end, the greater the deformation. By observing the deformation and stress distribution of the bellows, we can find the danger points of the bellows, which has important reference value for the design and maintenance of the bellows.

1. Introduction

Metal hose is the connection and compensation device in the complex piping system of chemical equipment. Which has many excellent properties such as reliable sealing, pressure resistance, high and low temperature resistance, corrosion resistance, flexibility and fatigue resistance, and plays the role of absorbing thermal deformation, vibration isolation and noise reduction. It has become an important component in a large number of refining devices. Its stable service has a continuous operation and safety of the device The whole production is of great significance [1].

When it comes to the research of metal hose, the traditional method mostly uses the theory research, Clark [2] uses the asymptotic integral method to calculate the axial displacement of shaped bellows. Anderson [3] used the asymptotic solution of Clark to develop the displacement stress solution of U-shaped bellows and evaluated the pressure stress, and introduced the correction coefficient according to beam theory and charts. Qian Weichang [4] proposed the general solution of the thin ring shell, and used the general solution to treat the bellows element as two thin ring shells, and gave the exact solution of the general axisymmetric problem of the ring shell. With the development of finite element technology, it is more and more common to use the finite element method to study the metal hose. In literature [5], the stress intensity distribution law of bellows is studied by the finite element method, and compared with the calculation results, it is proved that the finite element method is
reliable to study the bellows expansion joint. Wang Xinfeng's research group has also made a lot of achievements in the study of metal hose by the finite element method, which has important reference significance for the research of metal hose.

2. Brief introduction of metal hose model

According to the definition in GB/T 14525-2010 General specification for Corrugated metal hose assemblies, the metal hose is a combination of corrugated pipe, mesh sleeve and joint, or a combination of corrugated pipe and joint. The structural diagram of the metal hose is shown in Figure 1. Corrugated pipe is a cylindrical thin-walled shell with transverse corrugation, which is the main body of metal hose and plays the role of flexible deformation; the mesh sleeve is woven by several metal wires or metal belts with a certain spiral angle on the outer surface of the corrugated pipe and plays the role of strengthening and shielding; the joint plays the role of connection.

The material of mesh sleeve is the same as that of bellows, 0Cr18Ni9 (SUS304) is adopted, Modulus of elasticity \( E = 1.96 \times 10^5 \text{ Mpa} \), Poisson's ratio \( \nu = 0.3 \), Yield strength \( \sigma_y = 206 \text{ Mpa} \), Tensile strength \( \sigma_b = 520 \text{ Mpa} \). After processing, the yield strength of the material is increased after forming. Check the table and calculate the yield strength of the formed material \( \sigma_y = 328 \text{ Mpa} \).

2.1 Finite element model of metal hose

The structural parameters of the bellows include: the inner diameter of the straight side section of the bellows \( D \); Average diameter of bellows \( D_b \); number of layers of bellows \( n \); thickness of single layer of bellows \( \delta \); wave height \( h \); length of straight side section of bellows \( L_c \); wave distance \( q \); curvature radius of wave crest inner wall of U-shaped bellows \( r_c \).

In this paper, the material of bellows is 06Cr18Ni11Ti (321). Combined with the working condition of bellows, the structural parameters are designed according to GB / T 16749-1997 Bellows expansion joints for pressure vessel. The parameters are shown in Table 1.

| Table 1. Structural parameters of bellows. |
|-------------------------------------------|
| D  | D_b | q  | h  | n  | r_c | L_c | \( \delta \) |
| 200| 209 | 48 | 40 | 16 | 9.5 | 40  | 2.5        |

Three dimensional solid element SOLID185 is selected to build the three-dimensional solid model of multi-layer bellows, and the mapping grid is used to ensure that the cell grid has a better shape, and the contact pairs between layers are established.

The parameters of the metal net cover can be obtained from the empirical formula and GB/T 14525-2010 General specification for corrugated metal hose assemblies shown in Table 2:

| Table 2. Metal net cover weaving parameters. |
|---------------------------------------------|
| Braided angle | Number of shares | Root number per share | Wire diameter | Braided density | Layer number |
| \( \alpha \) | m | n | d | \( \lambda \) | c |
| 45° | 96 | 24 | 0.5 | 85% | 1 |
According to the structural characteristics of the wire mesh sleeve, the three node spatial beam element beam189 is adopted. The cross-sectional area of beam element is defined as circular section, and the cross-sectional area is equal to the cross-sectional area of each share. In order to simplify the calculation, the mesh sleeve model established in this paper is a single-layer model, so we choose to double the beam section, that is, the section diameter becomes 4.87mm.

3. Finite element analysis of bending displacement

During the working process of metal hose, the maximum stress and the most dangerous point of the bellows can not be observed directly, and the deformation can only be seen directly, so it is necessary to apply displacement load to study the maximum stress and dangerous point. Because the metal corrugated hose is a symmetrical structure, and the mechanical properties in all directions are the same, the structural force and displacement effect are the same. During the loading, one end is fixed, that is, all nodes are completely fixed, and the other end is applied with bending angle displacement. In the workbench software, the rotation y is set in the remote displacement of the static structure module, that is, the left end of the metal bellows is fixed, and the right end rotates around the y-axis. The stress nephogram and displacement nephogram of bellows are obtained by finite element analysis.

Calculate the stress, strain and deformation of bellows under the action of bending displacement, and determine the dangerous point according to the calculation results. The calculation state is shown in the table:

| Number | Boundary condition         | Displacement direction | Displacement angle |
|--------|----------------------------|------------------------|-------------------|
| 1      | One end fixed and one end free | Transverse             | 0.5               |
| 2      | One end fixed and one end free | Transverse             | 1                 |
| 3      | One end fixed and one end free | Transverse             | 2                 |
| 4      | One end fixed and one end free | Transverse             | 3                 |

4. Results and analysis

Calculation results under bending displacement condition

![Fig. 1 0.5 degree mises stress nephogram.](image1)

![Fig. 2 0.5 degree displacement nephogram.](image2)

![Fig. 3 1 degree mises stress nephogram.](image3)

![Fig4 1 degree displacement nephogram.](image4)
As shown in the figures above, the stress distribution rules of the four working conditions are similar. The stress distribution is concentrated in the fixed end and the free end of the metal bellows, and the maximum stress appears in the trough closest to the free end. And in the free end and fixed end of the bellows, the stress is large. The stress distribution in the neutral layer of the bellows is almost zero, and the angular displacement generated under the bending condition of the bellows is shown in the figure below. When the metal hose is subjected to the displacement or moment that makes it bend, it will generate the corresponding angular displacement in the axial plane, so the axis line of the bellows will become a deflection curve. As shown in Fig. 9, the bellows above the deflection curve is under tensile stress, and the ripples are in the expanded state; while the bellows under the deflection curve is under compressive stress, and the bellows is in the contracted state; the tensile stress and the compressive stress of the deflection curve itself are both zero, so it neither extends nor shortens, and always keeps balance, and only changes from the straight section of the initial state to the curved arc section.

By observing the displacement nephogram of bellows, it can be found that the displacement distribution of metal bellows is similar and regular under different loads. The closer to the free end, the greater the displacement. At the same abscissa, the closer to the neutral layer, the smaller the displacement. Because there is almost no stress in the neutral layer, the displacement of the neutral layer is smaller than that of the upper and lower sides.
As shown in the figure above, the curve of the maximum displacement and the maximum stress with the applied bending angle under the bending condition of four corrugated metal hoses. From the curve of the maximum displacement with time, it can be seen that the maximum displacement increases with the increase of bending angle, and presents a positive proportional linear distribution law. By observing the curve of the maximum stress and bending angle, it can be concluded that the maximum stress and bending angle also present a positive proportion distribution law in the range that the material can bear. The larger the bending angle is, the greater the stress at the dangerous point of corrugated metal hose will be until the material yield limit is reached.

It can be seen that under the four bending conditions, the greater the applied angular displacement is, the greater the maximum stress of the bellows is. The maximum stress is located in the trough closest to the free end, and the stress at the free end is relatively large, that is to say, under the action of torsional displacement, the acting end is a dangerous area; from the perspective of displacement distribution, the displacement at the same axial position is more inclined than its upper and lower positions small.

In the bending condition shown in above figure, draw the stress linearization curve along the thickness direction of the right end face, as shown in the right figure above, and separate the film, bending and secondary stress accordingly. The middle horizontal line is the film stress, the blue line is the primary film stress plus bending stress, and the orange line is the secondary stress curve. It can be seen from the stress curve that the stress of the outer layer network management is greater than that of the inner layer network management, and the bending stress is almost zero in the middle part, the outer layer is under tensile stress, and the inner layer network management is under compressive stress. The curve of primary stress plus bending stress and the curve of secondary stress are approximately symmetrical with the center of the thickness of the pipe network. Because there is a neutral layer in the middle of the metal corrugated hose when it is bent, the stress will be symmetrical with respect to the neutral layer, and the neutral layer will not be affected by the bending stress.

Analysis and comparison of inner and outer bellows results.
The calculation results of inner and outer layers with bending displacement of 3 degrees are shown in the following figure:

![Fig.14 inner Mises stress cloud.](image1)

![Fig. 15 outer Mises stress cloud figure.](image2)

From the cloud chart of Mises stress results in the inner layer in the figure, it can be seen that the stress distribution rules of the four working conditions are similar, the stress is mostly distributed at both ends of the bellows, there is a strip of low stress distribution area at the axis line, similar to the neutral layer, the stress is almost zero, and the middle of the bellows is also the low stress distribution area. This is because, on the axis line, the square bellows are in compression state, while the bellows under the axis are in tension state, and the bellows are in expansion state, and the position of the axis line is the neutral layer. The maximum stress is located near the first wave peak from the free end and at the bellows below the axis line, i.e. the tensile stress position.

From the cloud chart of Mises stress results in the outer layer in the figure, it can be seen that with the increase of bending displacement load applied, the maximum stress also increases, the fixed end and degree of freedom stress are larger, the net sheath appears neutral layer and the outer layer stress is larger than the inner layer stress.

### 5. Conclusion

In this paper, solid element solid186 and beam element beam189 are used to model the double layer metal hose with net cover, and the mechanical properties of metal corrugated hose under bending and torsion conditions are studied. By comparison:

1. The results of the finite element analysis of the metal hose under various load conditions show that the stress distribution of the metal hose is similar, and the stress intensity at the fixed end is large. When checking the strength of the bellows, the fixed end can be selected for checking. In actual installation, the fixed end shall be strengthened.

2. Under the load not exceeding the strength limit, the maximum stress and displacement of the bellows increase with the increase of the bending angle, and the distribution is linear.

3. Under the action of load conditions, the stress of outer bellows is significantly greater than that of inner bellows. Outer bellows and net cover have a certain protective effect on inner bellows. During the design and installation, the corrugated hose with net cover can bear more complex load conditions.

### References

[1] Edited by Ge Ziyu. Metal hose [M]. Beijing: Astronautic Publishing House, 1985

[2] Clark RA. On theory of thin elastic toroidal shells [J]. Journal of Mathematics Physicals, 1950,29:146-177

[3] Anderson W F. Analysis of Stresses in Bellows [A]. Part1, Design criteria and test result, NAA-SR-4527(Pt,1) [C], United States Atomic Energy Commission, 1964
[4] Qian Weichang, Zheng Siliang. Complex variable equations of axisymmetric circular shells and general solutions of axisymmetric thin circular shells [J]. Journal of Tsinghua University, 1979,19 (1): 27-47

[5] Liu Ying, Xu Hong, Gao Haitao, Shou Binan. The Application of the Design Method of U-Shaped Bellows by Finite Element Analysis [J]. Pressure vessel, 2001,18 (2): 30-33