Calculation Method of Flange Bolt Preload Based on Finite Element

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Abstract. Flange bolt connection is one of the most important connection modes in bolt connection at present. In this paper, the finite element model of the bolt between the shell and the head flange is established to analyze the influence of different initial preload on the bolt stress state under external load. The results show that according to the bolt stress state, the range of initial preload is divided into the influence area of the external load, the influence area of the resultant force and the influence area of the initial preload. In the influence area of external load, the bending moment exerted on the bolt dominates the stress state of the bolt, and the stress state of the bolt is poor, which is not the safe value area of the initial preload； in the influence area of the initial preload, initial preloads dominates the stress state of the bolt, the average stress of the bolt section is larger, and the bolt safety is smaller, which is not the safe value area of initial preloads; in the influence area of the resultant force, the bolt has better stress state and higher safety coefficient, which is the safety value area of initial preload. The initial preload corresponding to the boundary point between the influence area of the resultant force and the influence area of the external load and the influence area of the external load is the limit of the safe value range of the bolt preload.

Keywords: Flange bolt connection; Finite element calculation; VDI2230; Initial preloads.

1. Introduction

Bolted connection is the most common fastening connection in current industrial development [1]. High-strength bolts have the advantages of simple construction, high connection reliability, good mechanical performance, fatigue resistance, self-locking, disassembly and non-loosening under dynamic load, etc., and are increasingly widely used as a promising connection method [2]. Flange bolt connection is an important connection form of bolt connection, widely used in chemical industry, oil refining, nuclear power and other fields, with the advantages of convenient disassembly and maintenance [3]. However, in the process of bolt installation, improper handling will lead to sliding wire, twisting, yield, and even pulling, etc. Bolt breakage in the process of equipment operation will cause equipment damage, or even harm to personal safety [4,5]. Factors affecting the safety of flange bolt connection include flange strength, strength of optional bolts, bolt installation tools and methods, etc., among which insufficient bolt preload and improper installation method are the key factors [6,7]. Properly pretightening flange bolt connection can improve its sealing ability, anti-loosening ability, connection security, increase the tightness and rigidity of the connection, and prolong the service life of fasteners. Insufficient pretightening force will result in leakage of sealing surface and failure of flange seal under operating conditions, but too high pretightening force will also cause flange deformation, gasket collapse, bolt material yield and other problems, which will also lead to failure of flange seal [8].

At present, most scholars mainly use finite element software analysis[9-10] and scientific calculation to design and check the reliability of bolts. In this paper, the finite element method is used to analyze the force of bolts in flange connection, and a method to determine the initial preload of bolts is proposed, which provides a reference for determining the preload and preload torque of bolts in the installation process of industrial flanges.

2. Finite Element Calculation Model

In this paper, the flange bolts between the shell and the head of a certain equipment are taken as the research object (as shown in Fig.1). According to the symmetry of the shell and the head, the equipment 1/24 model is selected to establish the axisymmetric refined finite element model. The main body of the finite element model of shell and head is divided by hexahedral mesh, the transition region is divided by a small amount of wedge mesh, and the bolts and point gaskets are divided by hexahedral mesh. The finite element model contains 110458 elements, including 109966 hexahedral elements and 492 wedge elements.

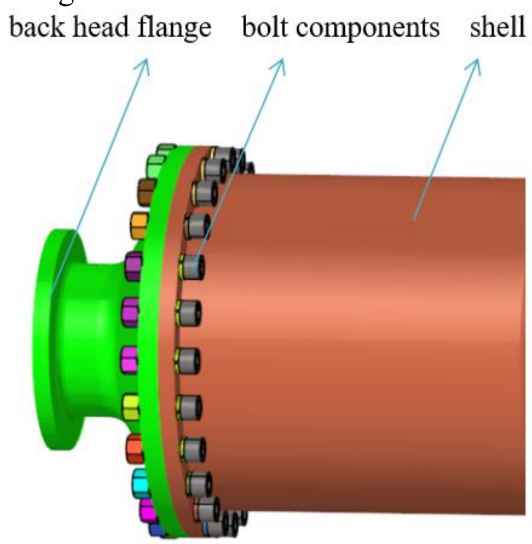

Figure 1. Three-dimensional Structure Diagram

Figure 2. Diagram of Finite Element Model

3. Material Properties and Boundary Conditions

3.1 Material Properties

The material of equipment shell and rear head is titanium alloy TB4, and the material of bolt is titanium alloy TB2(solid solution state), as shown in Table I.

Table 1. Material Properties Used in Finite Element Analysis

Project	TB4	TB2
Density [t/mm3]	4.5E-9	4.5E-9
Poisson's ratio	0.34	0.34
Elastic model [MPa]	108000	108000
yield strength [MPa]	825	838

3.2 Boundary Condition

The boundary condition parameters of the model are shown in Table II.

Table 2.Boundary Condition Parameters

Parametric	Numeral
Average diameter of sealing ring (Dcp)	392.3mm
The housing bears maximum working pressure (Pmax)	12MPa
specification of bolt	M20×75
Value range of initial preload F1	0-250kN

3.3 Loading Method of Initial Preload

In this paper, the temperature control method is used to apply the bolt preload, that is, when the finite element model is established, the temperature field is applied to the gasket and the thermal expansion coefficient along the bolt axis is set. By changing the temperature of the gasket, the thickness of the gasket is controlled to achieve the purpose of controlling the bolt preload. Figure 3 shows that the initial preload F1 varies linearly with the temperature change rate △t。

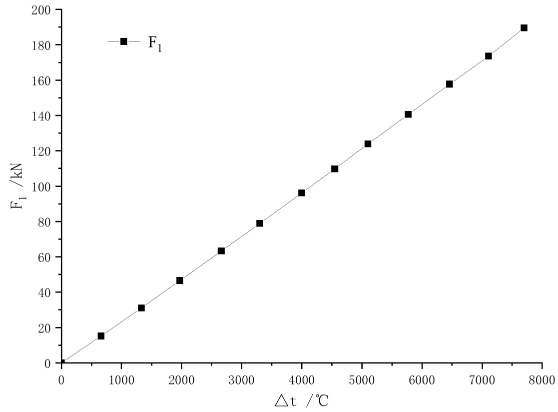

Figure 3. Relationship Between Initial Preload and Temperature Change Rate

4. Finite Element Analysis and Calculation Method of Initial Ireload

Under the action of working load Pmax, the bolt has three different stress states by applying different initial preload F1. When initial preloads is small, the influence of working load on the stress state of bolts is far greater than that of initial preloads, which is in a dominant position; when the initial preload increases to a certain extent, the working load and the initial preload jointly affect the stress state of the bolt. When the initial preload is large, the influence of the initial preload on the bolt stress state is far more than the working load, which is in the dominant position. According to the three stress states of the bolt, the range of the initial preload of the bolt is divided into three areas: the influence area of the external load, the influence area of the resultant force and the influence area of the initial preload.

In order to observe the deformation of bolt surface stress nephogram, the area with stress value exceeding 754.2 MPa in the bolt surface stress nephogram in Fig.4 is marked as gray. It can be seen from Fig.4 that when the initial preload value is in the influence area of external load, the gray area in the bolt stress nephogram is approximately triangular; as the initial pretightening force increases to the influence area of the resultant force, the grey area in the stress nephogram gradually changes from approximate triangle to ring. When the value of initial preloads further increases to the influence area of initial preloads, the gray area in the stress cloud image is completely transformed into a ring, and as initial preloads gradually increases, the gray ring area in the cloud image gradually expands. Comparing the stress nephogram of each region, it can be found that when the initial preload is in the influence area of the resultant force, the grey area in the stress nephogram is the smallest, indicating that the stress state of the bolt in the region is the best, so the influence area of the resultant force is the safe value range of the initial preload.

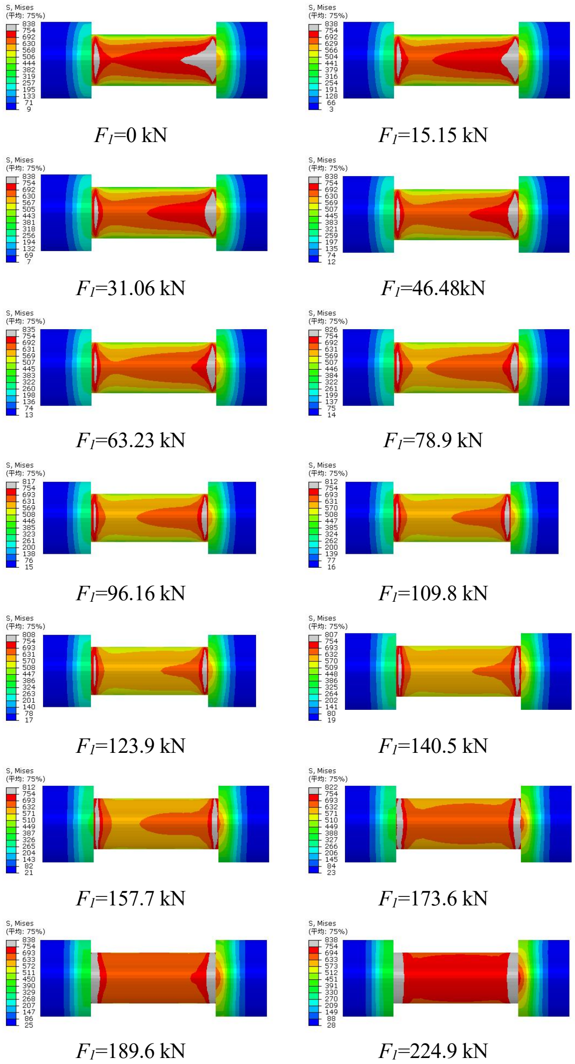

Figure 4. Stress Nephogram of Bolt Surface under Different Initial Preload F1

Fig.5 shows the corresponding relationship between the maximum value σ max and the minimum value σ min of the section stress at the middle position of the bolt and the initial preload. It can be seen from Fig.5 that the minimum stress of the section is mainly dominated by the initial preload, and it shows a linear growth trend with the increase of the initial preload in the range of F1>31.06 kN. The maximum section stress σ max gradually changed from linear decreasing trend to linear increasing trend in the process of initial preload increasing. Since the influence of the working load on the maximum stress of the section is much larger than that of the initial preload, with the increase of the initial preload, the bending moment applied by the working load on the bolt gradually decreases, and the maximum stress of the section shows a linear decreasing trend in the range of F1＜78.9kN,Therefore,F1<78.9 kN should belong to the influence area of external load; in the range of 78.9kN ≤ F1 ≤ 179.6kN, with the increase of initial preloads, the influence of the working load on the bolt continues to weaken, but the influence of initial preloads on the bolt continues to increase, which is sufficient to affect the maximum stress of the cross section and change the trend of the linear decrease of the maximum stress of the cross section, therefore, this interval should belong to the influence area of the resultant force; in the range of F1＜78.9kN, with the increase of initial preloads, the influence of the working load on the bolt can be ignored, and the maximum stress of the cross section is completely dominated by initial preloads, which increases linearly with initial preloads, therefore, this interval should belong to the influence area of initial preloads. Through the above analysis, it can be inferred that the two boundary points of the three regions of the external load influence area, the influence area of the resultant force and the influence area of the initial preload. should be near F1=78.9 kN and F1=179.6 kN. By fitting the corresponding equation of the curve, it can be found that F1=133.6 kN is the minimum value of the maximum stress of the section, and F1=133.6 kN is the best initial preload of the bolt.

Table 3 Stress on Bolt Section under Different Initial Preloads

F1/kN	σmax /MPa	σmin /MPa	σm /MPa
0	735	13.01	346.3
15.15	718.5	31.836	358.1
31.06	701.7	41.73	373.1
46.48	685.8	87.8	388.1
63.23	669.6	139.4	404.1
78.9	655.5	188.5	423.1
96.16	642.1	243.9	443.8
109.8	635.6	286.5	462.1
123.9	628.4	335.2	482.6
96.16	642.1	243.9	443.8
109.8	635.6	286.5	462.1
123.9	628.4	335.2	482.6
140.5	628.7	391	510.6
157.7	639.4	449.4	545.2
173.6	660.6	503.6	582.8
189.6	691.4	557.4	625.2
210.1	731.1	613.4	670.7
224.9	770.3	665.7	718.2

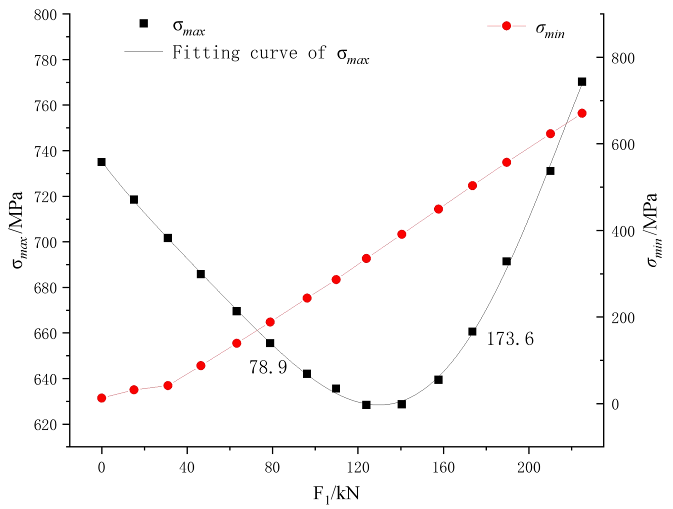

Figure 5. Variation Curve of σ max and σ min

Figure 6 is the fitting curve and derivative curve of the maximum stress and the minimum stress difference △σ initial preload F1. It can be seen from the figure that the extreme value of the derivative function of the stress difference △σ initial preload F1 is the maximum point of the stress difference △σ reduction rate, that is, the initial preload begins to affect the critical point of the maximum stress of the section, and it is also the critical point of he influence area of the external load and the influence area of the resultant force. The initial preload of critical point is 75.3kN by derivative curve. In engineering application, the average cross-section stress σm should not exceed 70%of the yield stress. Through the fitting curve of the average cross-section stress σm and the initial preload, the initial preload corresponding to the yield stress with the average stress equal to

70%is 175.1 kN. Therefore, F1=175.1 kN is the boundary point between the common influence area and the initial preload influence area.

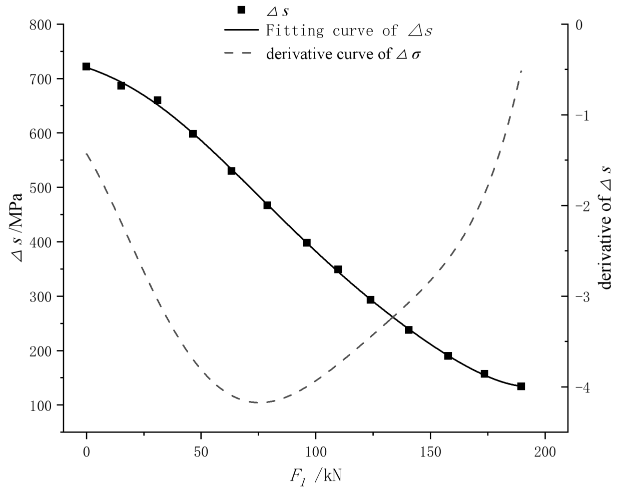

Figure 6. Fitting Curve and Derivative Curve of △ σ

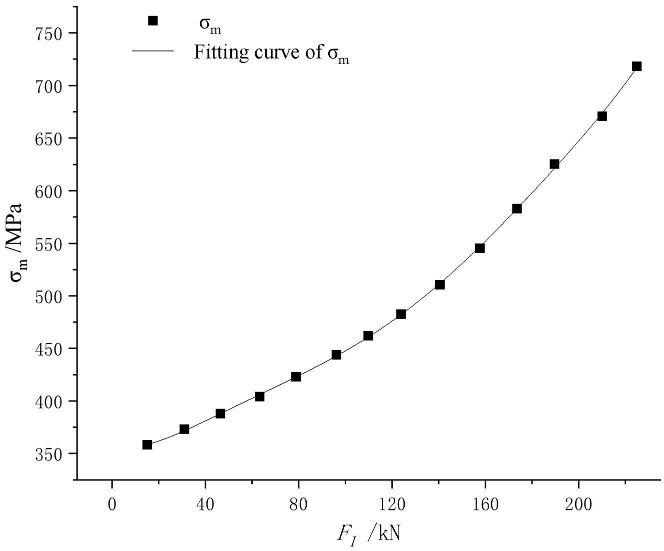

Figure 7. Fitting Curve of σ m

5. Conclusion

In this paper, the numerical simulation analysis of flange bolts on arc head and shell is carried out, and the following conclusions are obtained.

According to the three stress states of the bolt, the value range of the initial preload can be divided into three regions: the influence area of the external load, the influence area of the resultant force and the influence area of the initial preload.

The stress state of bolts in the influence area of the resultant force is the best, so the joint influence area is the safe range of initial preload, the initial preload corresponding to the boundary points of the influence area of the external load, the influence area of the resultant force and the influence area of the initial preload is the boundary divided by the safety value of the bolt.

The minimum initial preload and maximum initial preload of the head and shell flange bolts are 75.3 kN and 175.1 kN, respectively. However, in engineering applications, the optimum initial preload of the fastening head and shell flange bolts should be 133.6 kN.

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