

Intensity Analysis of Pretightening Bolt of Turntable Bearing

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Received: December 10, 2012

Accepted: January 9, 2013

Online Published: January 23, 2013

doi:10.5539/mer.v3n1p68

URL: <http://dx.doi.org/10.5539/mer.v3n1p68>

Abstract

This paper analyses the computation model of preloaded bearing which connects turntable bearing with Flange plate, provides the computation model which connects traditional utation model to the computation of turntable bearing directly. Adopting two ways of preload and service load, this thesis analyzes the maximum loading stress of every single bolt which is connects with turntable bearing. Analyzes and Computes the stress of bolt by utilizing finite element.

Keywords: turntable bearing, bolted connection, computation model, intensity analysis

1. Introduction

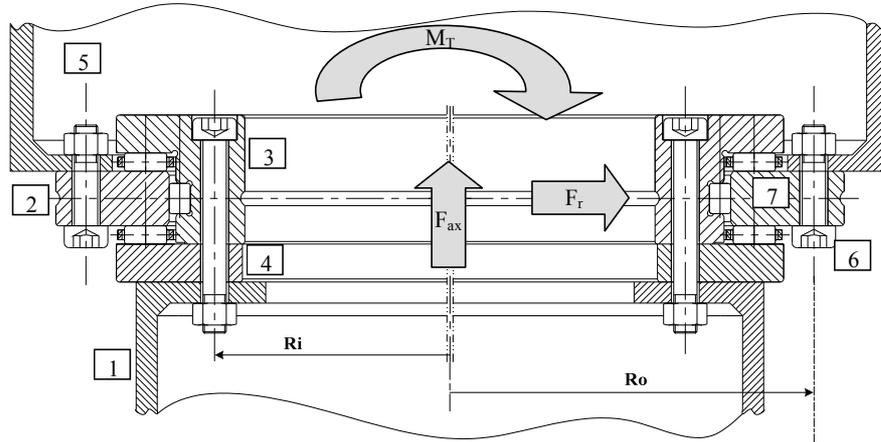
Turntable bearing which has larger size, is mainly used in elevating machinery, mining machine, building engineering machinery, turntable and so on. The turntable bearing is applied to connect two adjacent structures and allow turning and transferring load between adjacent structures (Guillot, 2005). Unlike most other bearing, turntable bearing has slow-speed of revolution, accompanying with intermittent and swing (Su, 2003). The bolt under pretension condition determines the connecting turntable bearing ferrule with flanges (Figure 1). The computation model of bolt under pretension condition combines traditional calculation method and finite element analysis.

The aim of pre-tightening of bolt is to enhance the reliability and tightness of the connection, so as not to occur the gap or relative slip during the connected elements. Experience shows that it is advantageous that the reliability of screw joint and fatigue strength of connector by appropriate selection of larger pre-tightening. However, overlarge pre-tightening could increase the size of the connector, and the connector may be snapped when assembly or overload (Pu, 2003). Therefore, in order to make pre-tightening of important screw joint enough below break load, we need control the pre-tightening when assembly (Combes, 2001).

The installation and use of turntable bearing depend on different exterior load conditions. For some applications, it is difficult to determine accurately what load the bearing get within the range of all service life. The load applied to the turntable bearing of wind power is one of the examples. Because more case studies can determine the range of the load, simulation and analysis of the load can be performed within bearing life. However, in order to calculate the work load of the turntable bearings and bolted connection, we generally define the axial force F_{ax} , radial force F_r and overturning moment M_T (Figure 1) in a simple way. The main purpose of this paper is to get axial stress distribution of the bolts at work through establishing actual shape and work load of the turntable bearing.

2. The Calculation of Pretightening Bolt Connection

Normally, the bolt connection during two different parts at least can be separable. Bolt connection is made up of bolts and nuts. The pretightening force is defined as the axial tensile stress F_M existing in the bolt connection before the work load is not applied to. Pretightening and dynamic load bolt connection is commonly used in different structures, especially in the most important part of the structure. Although there have been no generally accepted methods in calculation model of bolt connection, VDI 2230 is the most common method in engineering calculations.



1-Under flange; 2-Outer ring; 3-Inner ring; 4-The second inner ring; 5-Upper flange; 6-Bolt; 7-Rolling element

Figure 1. Role of external load on the turntable bearing

When the work load in the form of stretch is applied to the pretightening bolt connection, tensile stress applied to the bolt will increase compared to the preload generated in assembly. On the contrary the work load in the form of compressing is applied to the pretightening bolt connection, tensile stress applied to the bolts will reduce (as shown in Figure 2b). Based on assumption, the relationship between the usually assumed that the work load and force applied to the bolt is linear (Chen, 2003).

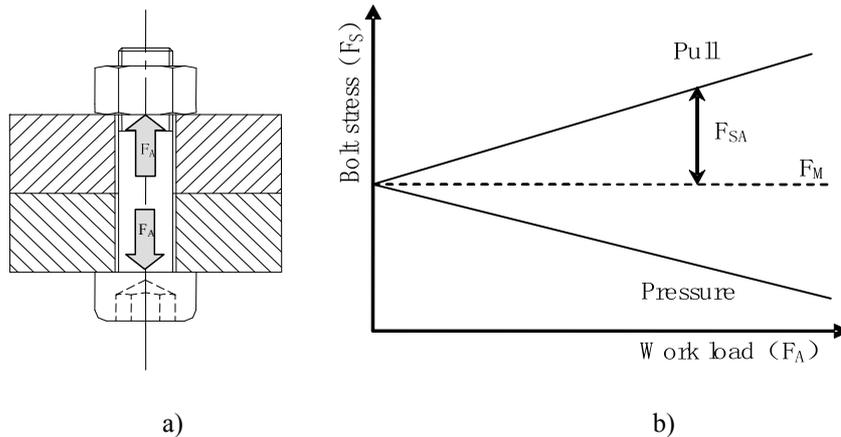


Figure 2. When the force applied to single bolt connection is in the same straight line, the relationship between the force applied to bolt and work load

In this case, the additional axial load of the bolt F_{SA} can be calculated as follows:

$$F_{SA} = \Phi \cdot F_A = n \cdot \frac{\delta_p}{\delta_s + \delta_p} \cdot F_A \tag{1}$$

Φ is relative elasticity, n is loading coefficient. Load of bolt is made up of assembled loads F_M and additional axial load of bolt F_{SA} :

$$F_S = F_M + F_{SA} \tag{2}$$

As is shown in equation 1, before quantitatively pretightening bolt connection analysis, it is necessary to know the bolt stiffness δ_s which can be easily calculated by analytical methods and stiffness of connected part δ_p (The calculation of Formula 1, δ_s and δ_p reference to ‘The computing method of bolt additional load when the bolt

group coupling relieve transverse bending moment', 1990). There are a variety of different models to describe volume changes and the stiffness of all the parts when all the parts of the bolt are pressured. These models are mainly used in finite element analysis and experience accumulation.

It is very difficult that these computation models are directly applied to the calculation of bolt pretightening in the turntable bearing. The main reason is as follows:

The analytical model for the single bolt connection which clamping position center and center of force in a straight line (cylindrical or diamond studs) is effective, and it allows that both the center positions have a smaller eccentricity. This indicates that the vertical axis of the work load should be very close to the center axis of the bolt. On the contrary, when the eccentricity between the center of the clamping position and force center is very various, cross section of the connector or turntable bearing rings will produce complex deformation.

Additional load of the bolt can be determined by the load coefficient in Equation 1. The load coefficient can be calculated for basic geometry and load conditions because of intensive study of the parameters. However, the load coefficient can not be accurately calculated for many examples, of course, including bolt connection of turntable bearing. Therefore, the load coefficient is very important to solve force of the uncertain bolt.

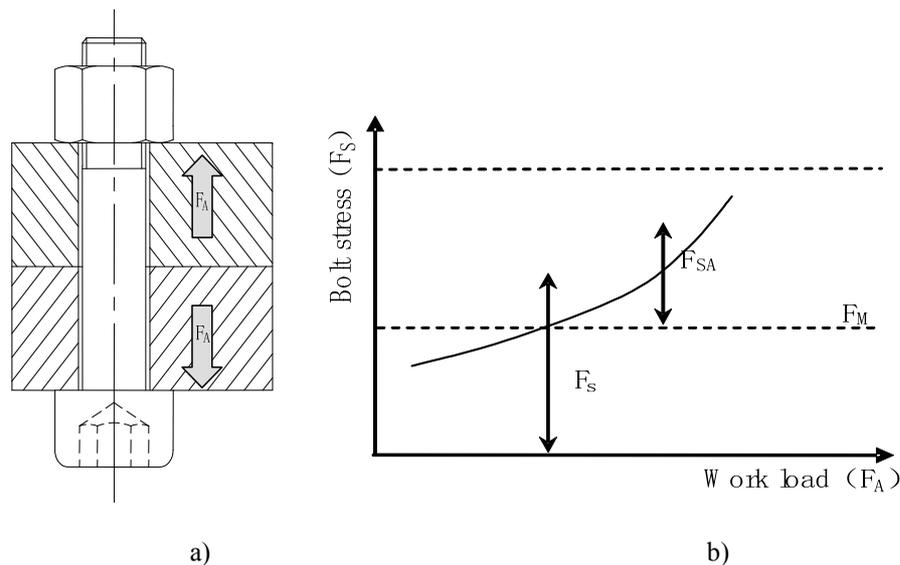


Figure 3. Center of Force deviate from Center of bolted connection (a) chart of nonlinear relationship between F_A and F_S

Some scholars (Frese, 2000) pointed out that the load eccentricity of partly bolt connection change constantly when the turntable bearings are busy and stressed. There are only some approximate solution methods in processing the load eccentricity changes of pretension bolt connection. The eccentricity change of bolt connection is one of the reasons for the non-linear relationship between the work load and bolt load (Figure 3b).

Existing computation model mainly aims at the single bolted connection. Normally, these calculation models can not help solve the work load F_A . In this study of turntable bearing, especially in the instance of existing the overturning moment, the force of every bolt is different. Thus, solving the work load requires some other methods.

Some scholars propose a numerical method in the possible methods for solving pretightening bolted connection of turntable bearing, which introduce the finite element analysis method. This model compromises several simple arithmetic methods about finite element simulation of contact and bending.

3. Computation Model

Under normal circumstances, there are two basic ways to analyze and use the connection of the ferrule and the flange of a plurality of bolts (for example, turntable bearing). One method requires the entire ferrule model (Figure 4a), the other method is to consider the same portion of the most Loading bolts (Figure 4b). The two methods have both advantages and disadvantages.

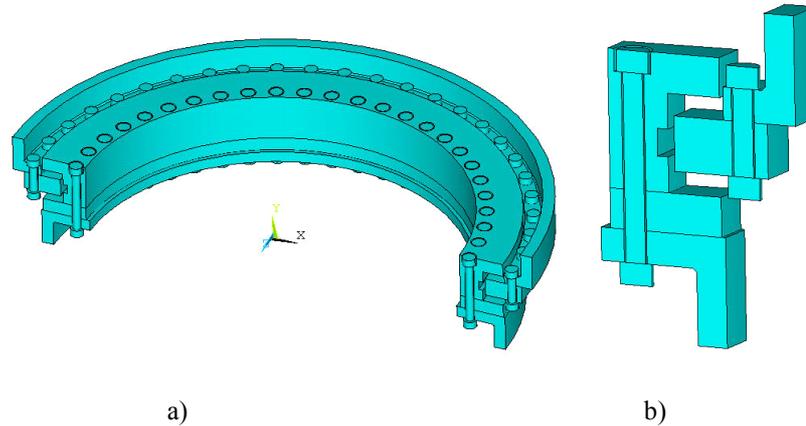


Figure 4. The assembly model of entire turntable bearing and flange(a) and the bolted connection of the same corresponding portions(b)

3.1 Computation of Work Load

The modeling and analysis of the entire bearing rings and the substructure connected to bearing rings can accurately calculate the force of key nodes of the bolt, and the calculation include the elasticity of the connecting structure in the direction of the axis of the bolt. When the substructure is very complicated and can not regard it as an ideal rigid body or its stiffness is variable, this calculation method is very important. When considering random defects of Ferrule geometry in the analysis, model should also be overall built.

On the other hand, when the bolts are distributed evenly around the ferrule, then the support is rigid or hollow and has no hard-spot, it is available for the modeling of the force of the largest portion. This method usually overestimates the force of the largest portion. Therefore the method can not calculate any stress of redistribution when stressed center deviate from the bolt axis (Li, 2009). In these examples, the following equation can be used to calculate and analyze the work load F_A of the maximum stressed portion:

$$F_A = \frac{1}{\cos \beta} \left(\frac{2 \cdot M_T}{\pi \cdot R} \cdot \sin \frac{\pi}{z} + \frac{F_{ax}}{z} \right) \quad (3)$$

β is the angle between the work load F_A and the bearing axis (Figure 6), z is the number of bolts distributed evenly around the bearing, R is the radius of the bolt (Figure 1).

3.2 Finite Element Model of the Ferrule

Due to geometric symmetry, only half model of the maximum stressed bolted connection is built. Using the finite element software ANSYS is to build the model. The analysis portions of model include ferrule (inner and outer) of turntable bearing, the connection components (flange) and the bolts (Figure 5).

There are different modeling methods for the bolts and pretightening bolts in the finite element analysis. Depending on the accuracy of the got results, the bolts can be built in one-dimensional beam elements, solid elements or a combination of them. When the entity are built of bolts, different studies show that acceptable results can be got even if the bolt head is not modeled in detail. According to this result and other similar analysis in the existing model, the entity model composed by three parts (bolt head, studs and nuts) is built of the bolts.

The use of finite element software provides a tool for simulation analysis of the bolted preload. Thus, the preload and the external load of bolted connection can be easily and visually simulated. The relationship between the work load and ferrule axial direction is $\beta=0^\circ$, and act on the surface of the channel as a constant pressure. In the vertical and tangential direction the contact is defined as follows (Figure 5a):

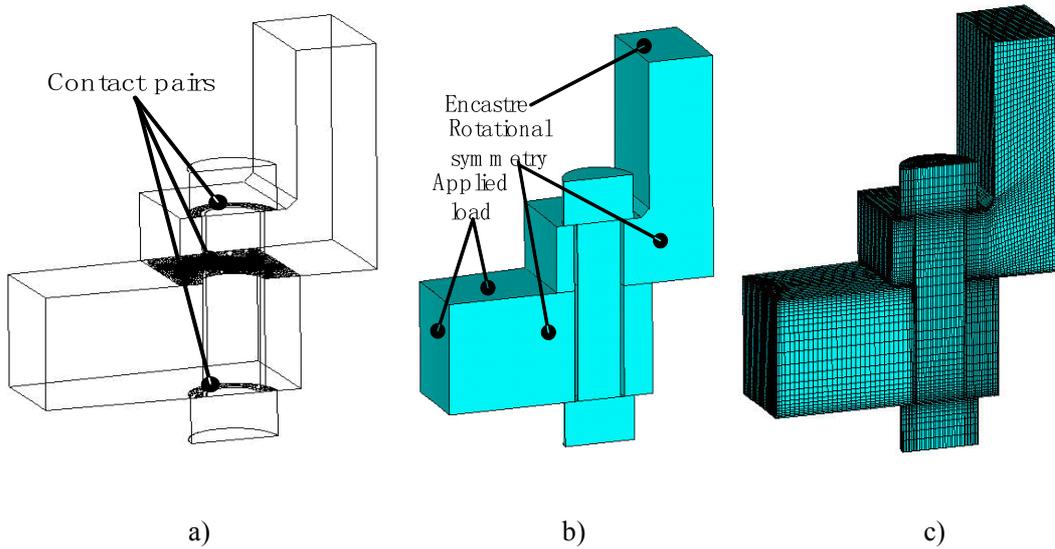


Figure 5. The defined contact of the connected parts(a), boundary condition(b) and grid model (c)

In Figure 5 (a) the contact pairs contain bolt head and ferrule, ferrule and flange (detachable under load), nut and flange. In this finite element analysis, the linear elastic material model ($E = 207 \text{ GPa}$, $\mu = 0.3$) is applied. The model grid use the unit of 8-node sliod45 (Figure 5c).

4. Practical Examples

In this case, inner and outer rings of turntable bearing made up of cylindrical roller and thrust needle roller are analyzed. Geometric characteristics of the turntable bearing applied to finite element model grow from the list of a manufacturer, and its parameters are as shown in Table 1. In the modeling (half of the whole turntable bearing), there are 24 bolts that the angle between the bolt axis and the bearing centerline is 7.5° . The size of the bolt is M8 and the requirement of strength grade is 10.9 (yield strength of the bolt material is 800 MPa).

The overturning moment of the turntable bearing is $M_T = 7 \text{ kN}\cdot\text{m}$, the axial force is $F_{ax} = 23 \text{ kN}$, and radial force is $F_r = 15 \text{ kN}$. The selection of these values is based on the critical load curve of the bolt applied to specific bearing in the manufacturer lists. The load of work load converted into by external load on a bolt is as follows:

Table 1. The main parameters of turntable bearing used in the finite element model

	Outer/inner ring
Ring diameter (mm)	525/486
Ring width(mm)	65(The first inner ring50.5, The second inner ring14.5)/20
Bolt set diameter(mm)	415
Numbers of bolts(mm)	24
Flange thickness(mm)	12

The force condition of largest stressed bolts on the outer ring:

The corresponding bolted force of overturning moment

$$F_{out_T} = \frac{2 \cdot M_T}{\pi \cdot R} \cdot \sin \frac{\pi}{z} = \frac{2 \times 7}{3.14 \times 207.5} \cdot \sin \frac{3.14}{45} \times 10^6 \text{ N} = 4672.7 \text{ N}$$

The corresponding bolted force of axial force

$$F_{out_ax} = \frac{F_{ax}}{N_1} = \frac{23}{45} kN = 511.1N$$

The corresponding bolted force of radial force

$$F_{out_r} = \frac{F_r}{N_1} = \frac{15}{45} kN = 333.3N$$

The force for each bolt on the inner ring:

The corresponding bolted force of overturning moment

$$F_{m_T} = \frac{2 \cdot M_T}{\pi \cdot R} \cdot \sin \frac{\pi}{z} = \frac{2 \times 7}{3.14 \times 207.5} \cdot \sin \frac{3.14}{46} \times 10^6 N = 4572.7N$$

The corresponding bolted force of axial force

$$F_{in_ax} = \frac{F_{ax}}{N_2} = \frac{23}{46} kN = 500N$$

The corresponding bolted force of radial force

$$F_{out_r} = \frac{F_r}{N_2} = \frac{15}{46} kN = 326.1N$$

Axial stressed analysis of the bolts is shown as follows. There are mainly three steps:

- preload of the bolts (Figure 6a)
- tension load of the bolts (Figure 6b)
- pressure load of the bolts (Figure 6c)

The preload reaches $\sigma_M = 0.7 \cdot R_p 0.2$ (bolt material yield strength), and the value is 560 Mpa, that is to say, each bolted preload is

$$F_T = \sigma_M \cdot \frac{1}{4} \pi D^2 = 28148.7N$$

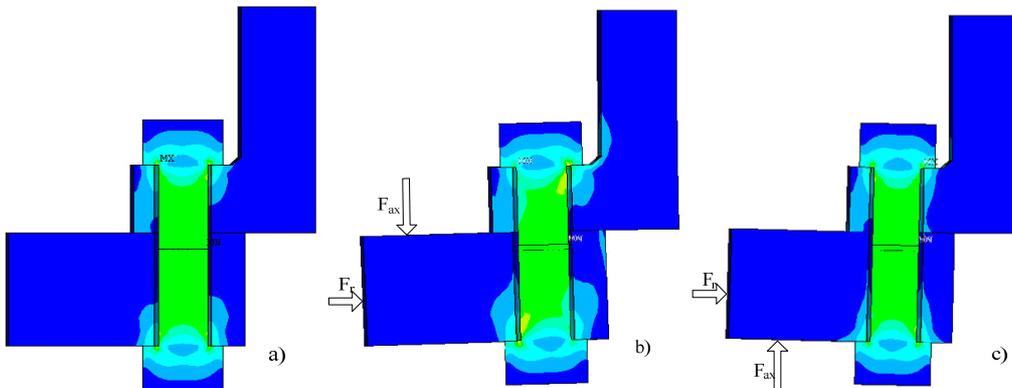


Figure 6. There are three steps in the part of finite element analysis of rings: -preload of the bolts (a) -tension load of the bolts (b) -pressure load of the bolts (c)

Other scholars (Liu, 2006) in their research indicate that the higher preload is advantageous to bolted connection, which can decrease the alternating stress of the bolts, reduce the risk of loose connection and slower the start time of loosening due to lateral load (Chaib-Zouhair, 2007). In this experiment, it is simulated to determine the importance of two different preloads: when the preload reach $\sigma_M = 0.5 \cdot R_p 0.2$ (yield strength of bolt material), the value is 400 Mpa, and when the preload reach $\sigma_M = 0.7 \cdot R_p 0.2$ (yield strength of bolt material), and the value is 560 Mpa.

5. Computation Results

Based on numerical results of Bolted connection (inner and outer ring) the axial stress distribution on the bolts is as follows. Observed the stress distribution at both ends of the entire height in the bolted connection, the both ends is the beginning and ending of the stud in the bolted connection that geometric shape of the bolts will change acutely (Figure 6).

The maximal working stress σ_s and maximal alternating stress σ_a can be got from the acquired stress distribution. The maximal working stress σ_s at both ends of the bolt can be directly obtained from the results, and the results show the maximum value of axial stress and both sides of the bolt (a and b in Figure 7) are considered. Maximum working stress σ_s should be lower than the yield strength of given bolt material. In this example, the level of bolt strength is 10.9, that is to say the yield limit is $R_{p0.2} = 800$ Mpa.

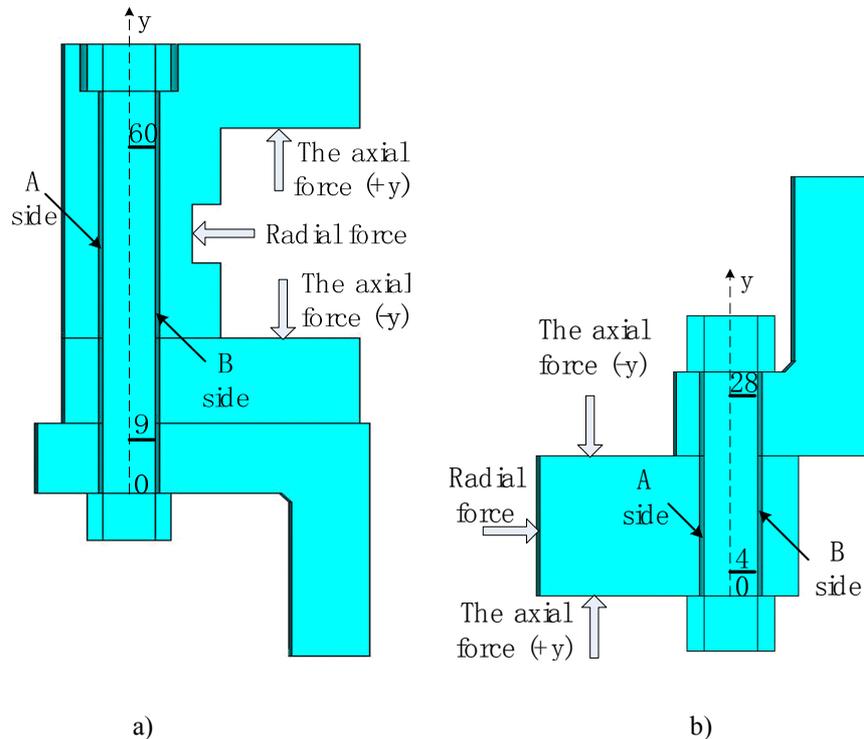


Figure 7. Stressed distribution of the bolts: the inner ring (a) and the outer ring (b)

The amplitude of alternating stress σ_a affect the fatigue life of bolt, and the amplitude must be less than the fatigue limit in the entire fatigue cycle (the numbers of alternating cycles $> 2 \cdot 10^6$). The Formula of the alternating stress σ_a :

$$\sigma_a = \frac{\sigma_{Smax} - \sigma_{Smin}}{2} \quad (4)$$

In the equation, σ_{Smax} is the maximum value of the axial stress, σ_{Smin} is the minimum value of the axial stress. In the bolted model the maximum σ_{Smax} and the minimum σ_{Smin} can be respectively got in the node of axial stress. The result shows that the alternating stress value of each node in the axial direction of the bolt can be obtained (on both sides of the stud). The maximum value can be determined on both sides of given alternating stress of the bolts.

Fatigue limit of high Strength bolts according to VDI 2230 (σ_{ASV})

$$\sigma_{ASV} = 0.85 \left(\frac{150}{d} + 45 \right) \quad (5)$$

This shows that fatigue limit σ_{ASV} of the bolt whose size is M8 is 54.2Mpa, then alternating stress applied to bolts should be lower than the limit.

Table2. The forces of outer bolts under cyclic loading

A side	Size(mm)	4	8.8	13.6	18.4	23.2	28	Max σ_a (MPa)
0.5·R _p 0.2	Only pre-load	405.4	403.2	400.6	398.4	394.7	359.6	70.5
	Force(-Y)	457.9	432.2	406.6	381.6	355.1	300.6	
	Force(+Y)	387.5	393.5	398.5	404.0	407.9	379.7	
0.7·R _p 0.2	Only pre-load	565.9	563.7	560.7	558.4	553.8	505.4	31.3
	Force(-Y)	584.3	573.6	562.5	552.1	539.6	484.0	
	Force(+Y)	553.0	556.8	559.4	562.7	563.7	520.4	
B side	Size (mm)	4	8.8	13.6	18.4	23.2	28	
0.5·R _p 0.2	Only pre-load	400.6	402.8	404.6	406.9	407.6	375.7	69.2
	Force(-Y)	348.6	374.0	398.6	423.8	447.2	433.9	
	Force(+Y)	417.8	412.5	406.7	401.3	394.4	356.8	
0.7·R _p 0.2	Only pre-load	562.3	564.8	566.6	569.1	569.3	524.3	29.9
	Force(-Y)	544.6	555.0	564.8	575.3	583.5	544.5	
	Force(+Y)	574.5	571.6	567.8	564.8	559.5	510.5	

Table3. The forces of inner bolts under cyclic loading

A side	Size(mm)	9	15	27	39	51	60	Max σ_a (MPa)
0.5·R _p 0.2	Only pre-load	399.0	399.4	399.2	399.1	398.8	398.3	14.9
	Force(-Y)	399.2	399.7	399.7	399.6	399.6	399.2	
	Force(+Y)	384.3	385.6	387.2	388.8	390.3	391.1	
0.7·R _p 0.2	Only pre-load	558.6	559.2	558.9	558.7	558.4	557.7	9.6
	Force(-Y)	558.7	559.4	559.3	559.2	559.1	558.5	
	Force(+Y)	549.1	549.9	550.1	550.2	550.3	549.9	
B side	Size(mm)	9	15	27	39	51	60	
0.5·R _p 0.2	Only pre-load	402.5	403.7	404.1	404.2	404.4	403.2	14.8
	Force(-Y)	402.3	403.4	403.6	403.6	403.7	402.4	
	Force(+Y)	417.1	417.4	416.1	414.5	412.9	410.4	
0.7·R _p 0.2	Only pre-load	563.5	565.2	565.7	565.9	566.2	564.5	9.6
	Force(-Y)	563.4	565	565.3	565.4	565.5	563.7	
	Force(+Y)	573.0	574.4	574.5	574.3	574.2	572.1	

The maximum axial working stresses σ_s in the outer ring of bolts are 457.96Mpa ($\sigma_M = 0.5 \cdot R_p0.2$) and 584.32 MPa ($\sigma_M = 0.7 \cdot R_p0.2$). The maximum axial working stresses σ_s on the inner ring of bolts are 417.4 Mpa ($\sigma_M = 0.5 \cdot R_p0.2$) and 559.4MPa ($\sigma_M = 0.7 \cdot R_p0.2$). The actual concrete data is given in Table 2 and Table 3. According to these results, the axial working stress σ_s is lower than permissible value (800 Mpa) of the bolts in these cases.

Meanwhile, in the process of loading (tensile stress is $0.5 \cdot R_p0.2$), the maximum alternating stress of the bolt in contact with the outer ring is 70.51 Mpa, and in the inner ring is 14.9 Mpa. When the tensile stress reach $0.7 \cdot R_p0.2$, the alternating stress on the ferrule reduce respectively 31.33 Mpa in the outer ring and 9.6 Mpa on the inner ring. The alternating stress conforms to the confirmed hypothesis: Larger pretension has the positive impact on the amplitude of alternating stress. Considering the analysis results, the pretension of bolt is $0.5 \cdot R_p0.2$, and the bolt alternating stress (σ_a) connected to the bearing outer ring is higher than the fatigue limit σ_{ASV} (54.2 MPa)

of the bolt M_8 .

6. Conclusion

The computation model of this paper is the pretightening bolted connection on the turntable bearing. Because of specific clamping means and load condition about turntable bearing ferrule, it is not accurate that stress condition of the bolted connection is calculated by conventional pretightening bolted connection method in the model. The computation model uses finite element analysis to obtain the axial stress distribution in loaded bolt. The axial working stress σ_s and alternating stress σ_a can be got from these results. The two stresses are basic strength requirements for pretension bolted connection.

The working load F_A which should be as the main objective determines the relationship between the working load F_A and bolted load F_S in further research. As many scholars can see, treating the support as an ideal rigid body is an over-simplification in some cases. Contact and geometry of the bolts should be also considered besides intensively the impact of physical material, which could greatly enhance the application of the results.

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