The Study of Bolt up Sequence Influence of the Bolted Assembly Structure Contact Stiffness

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Abstract. According to the existence problems of study on the mechanism of contact stiffness of bolted assembly structure formed by tightening sequence, a TK model of single bolt structure is established; then the frequency characteristics of combined surface under different TS was analyzed by using ANSYS; the optimal TS is obtained based on the frequency and the interface stiffness mapping. At last, a group of experiments was done to verify the above conclusions. The results show that the interface stiffness is verify under different TS, and so does the first rank natural frequency of the structure; the nonlinear response of the structure is significantly affected by TS that tighten at the same time is the optimal method compared with other TS. A small error of modal frequency between simulating and testing proves that the modeling method can effectively analyze impacts of the TS on the dynamic properties of the interface.

Introduction

Currently, the machinery and equipment toward precision, complex, intelligent development, its precision assembly and maintenance of theoretical technology has been considerable development. However, the gap of maintenance and precision assembly process between the world and home is still large, which faced contradiction of advanced production and processing capacity and backward parts of the assembly and maintenance processes for a long time, such as aircraft engines. In a large number of complex mechanical systems existence joint surface, its dynamic performance has a significant impact on the quality of assembly and maintenance.

Many scholars have made a lot of research in this area. Andrew et al. [1] proposed a combination of surface oil free method to move closer to the normal stiffness static stiffness, which come to the simplified method to calculate per unit area contact stiffness and tangential contact stiffness empirical formula. Muhammad al [2] uses the finite element method simulation of bolt preload in the load history, and optimize the level of preload applied sequentially, and other key process parameters. Wang Wei et al[3] using the method of reverse engineering to establish a correlation model bolt preload size, speed and connectivity, which guiding the assembly process for precision bolt connection.

However, most of these studies are based on the finite element method, the influence of process factors on the dynamic performance of the joint surface lack of experimental verification in theory. Firstly, establish an analytical model of tightening torque and the joint surface stiffness, combined with the finite element simulation. Finally, we experiment the verification.

TK model

Andrew et al. proposed an empirical formula, which is a unit area normal contact stiffness and tangential contact stiffness of degradation:

$$\begin{cases} k_n = \alpha_n p_n^{\beta_n} \\ k_\tau = \alpha_\tau p_n^{\beta\tau} \end{cases} \tag{1}$$

I.e., $k_i = \alpha p_i^{\beta} \Delta s$ (2)

Where: k_n —the normal contact stiffness; k_τ —tangential contact stiffness; p_n —combined surface normal pressure; α, β—the combination of surface constant; k_i, p_i—the combined stiffness and pressure surface of i node; Δs —node grid area, depending on the mesh size.

Thus combining surface stiffness can be expressed as:

$$K = \sum_{i=1}^{m} k_i = \frac{\alpha S}{m} \sum_{i=1}^{m} p_i^{\beta} \tag{3}$$

Where: S is bolted joint surface area effectively under pressure, m is the total number of grid. Figure 1 is a typical single screw connection structure, fig. 2 is a connector member that is being sought. From the literature [7] can be obtained:

$$r_b = \frac{\int_{r_{\min}}^{r_{\max}} r^{1.9} P\, dr}{\int_{r_{\min}}^{r_{\max}} r^{0.9} P\, dr} = \frac{\sum_{n=1}^{m} r_n^{1.9} P_{r_n}}{\sum_{n=1}^{m} r_n^{0.9} P_{r_n}} \quad (m \to \infty, r_n = r_{\min} + \frac{n(r_{\max} + r_{\min})}{m}) \tag{4}$$

$$S = \pi (r_b^{\,2} - r_a^{\,2}) \tag{5}$$

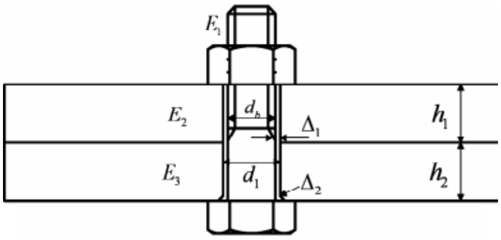


Figure 1 a single bolt connection diagram

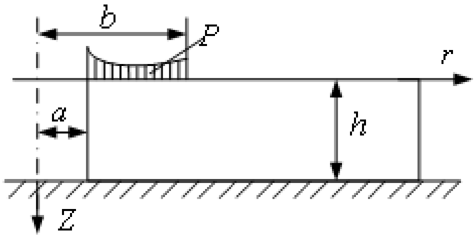


Figure 2 is force diagram connector

After the relationship ended bolt tightening bolt preload between the bearing surface pressure distributions is as follows:

$$F = \int_A P\, dA = 2\pi \int_{r_{\min}}^{r_{\max}} rP\, dr \tag{6}$$

Mottos proposed a T_F method of calculation does not consider the lead angle of the bolt, such as the formula (7) below:

$$\begin{aligned} T &= (\frac{p}{2\pi} + \frac{\mu_t r_t}{\cos\beta} + \mu_b r_b)F \\ &= \frac{p}{2\pi}F + \frac{\mu_t r_t}{\cos\beta}F + \mu_b r_b F \\ &= T_p + T_t + T_b \end{aligned} \tag{7}$$

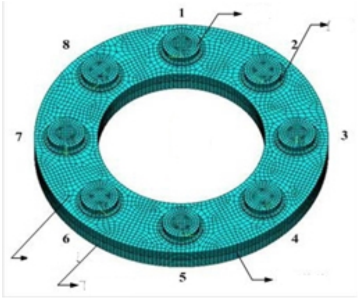
Where: T—tightening torque; F—preload final form; p—pitch; μ_t —thread Friction coefficient; μ_b —coefficient of friction between the bolt bearing surface; r_b—the effective radius of the bolt bearing surface; r_t—the effective radius of the thread; β—thread half angle, according to the ISO standard, tooth type half width for 30°; T_p—eventually formed preload torque; T_t—tightening process to overcome the thread friction torque; T_b—tightening process to overcome the friction torque bolt bearing surface.

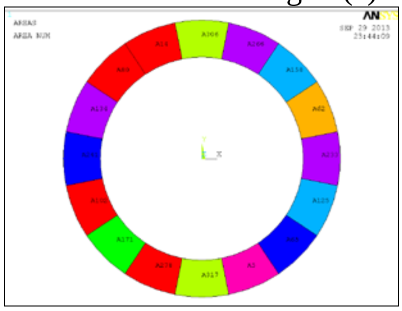
So we have established the TK model of single bolted by the relationship form T_F_P_K.

The Influence of tight sequence of assembly

Bolt assembly connection often used in a group, as a result of interspecific structure of the thread and the bolts mutual elastic effect, tighten the bolt to be tightened bolt preload will have some impact on quality of the connection of different tightening sequence generated can are not the same.

Specimen model. Here take the same tightening torque T uses a different tightening strategies object, which was bolt group ring evenly distributed, a total of eight M12*1.75 bolts, strength class 10.9, up and down the board, middle gasket and bolt materials and the previous section table 2_1 identical. The basic construction of the finite element model and the same model of a single bolt preload, but obviously for the elastic interaction, the paper TBPT segment definition of the stress strain curve of the gasket, the gasket take mesh units mapped meshing, its finite element model Fig. 3 (a).

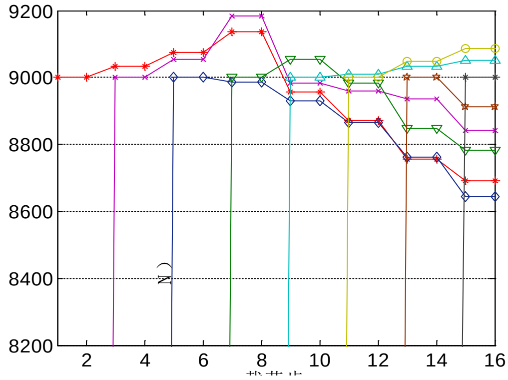


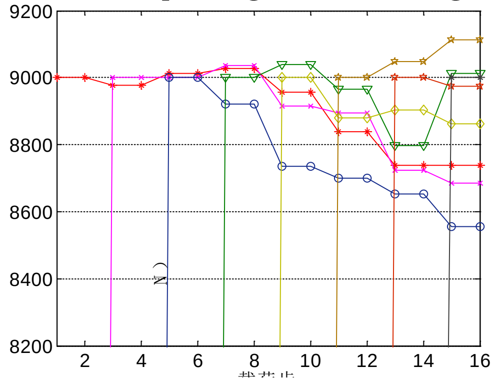


(a) finite element model of the flange connection (b) the contact area Flanged

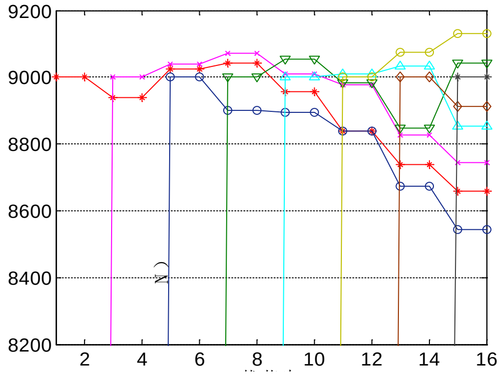
Figure 3 flanged models

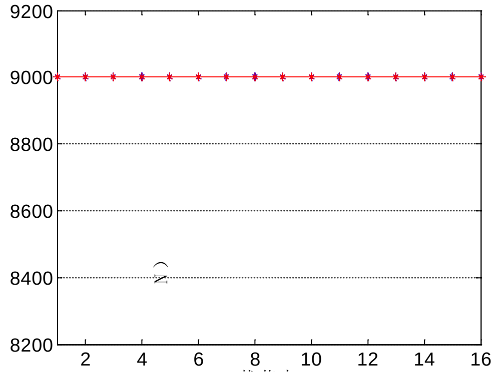
The results of tightening. Tighten the bolt tightening sequence settings to control the use of load step, a total of 8 bolts, applying a load in step 2*i*_1, load 2*i* lock step. Bolt annular distribution symmetrical structure, its tightening sequence points four cases: Tighten order 1_2_3_4_5_6_7_8; interval tightens 1_3_5_7_2_4_6_ 8; diagonal tighten 1_5_3_7_2_6_4_8; at the same time tighten. 9KN bolt preload applied to extract each bolt preload with the load step changes shown in Figure 4.





(a) diagonal sequence tighten (b) interval sequence tighten





(c) tighten the sequential order (d) at the same time tighten

Figure 4 different preload tightening sequence varies with load chart

Various end screwed tight manner when calculating the standard deviation of the bolt clamping force, obtained σat the same time tighten are 0, σ diagonal sequence tighten are 164.9, for σ interval sequence tighten are 192.6, σ Tighten the sequential order are 201.2.

Therefore, only the preload distribution is uniform standards bolted joint surface tightening effect, at the same time tighten the diagonal tighten interval tighten, tighten the tightening effect favorably to the poor in order of priority.

Flange connections modal simulation. As can be seen from Figure 4, a different sequence of tightening the bolts the final clamping force is not the same, the model derived from the combination of surface TK equivalent stiffness K is a difference, and with the increase of the clamping force.

Select 20KN preload applied to the bolts, tighten the order of different (standard deviation divided) on the flange of the first natural frequency. Extract and calculate the bolt preload averages between 19.91 ~ 20.03KN, or less, but at the same time tighten diagonally tightened, spacing and order of tightening preload standard deviation were 0,0.2713,0.4029 , 0.6147, and tighten the correspondence between the order of the first natural frequency and shown in Figure 6.

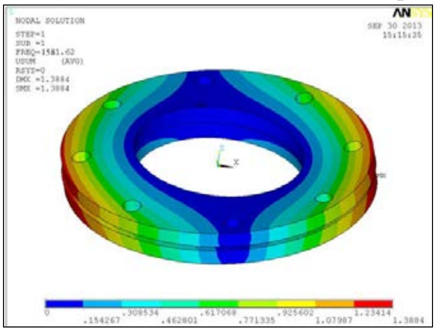


Figure 5flanged modal response

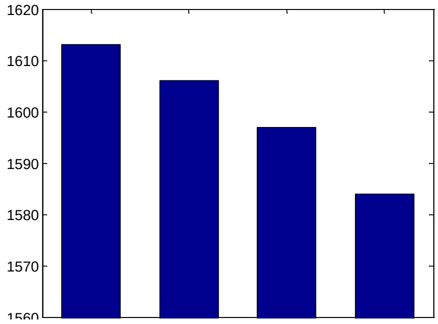


Figure 6 screwed tight influence of the first natural frequency of the order value

At the same time tighten the figure shows, the diagonal tighten interval tighten sequentially tighten each bolt preload standard deviation in turn increases the modal frequencies flange structure is gradually declining. Simulation data show that each bolt group fairly average preload, the preload standard deviation smaller group connection bolt joint surface more uniform pressure distribution, the greater the overall structure of the modal frequency value, the greater the overall connection stiffness .

Summary

Firstly, analytical method established by the bolt tightening torque and stiffness of the joint surface TK association model, and then using the finite element simulation method to analyze the influence of different sequence of tightening bolted assembly stiffness, and finally experimental verification results:

Bolt tightening torque and stiffness combined with a nonlinear relationship between surface contact, and K as T increases, when it reaches the vicinity of the bolt material yield point does not change the value of K (small changes); a different assembly process (tightening order) bolted assembly performance (preload distribution) has a significant impact, while tightening the best diagonal tighten, tighten interval, followed by the order to tighten the worst; TK model is established and then come to the right can be used as a further theoretical calculation method were analyzed solver.

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