

# A Modelling Method of Bolt Joints Based on Basic Characteristic Parameters of Joint Surfaces

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**Abstract.** Bolt joints are common in machine tools and have a direct impact on the overall performance of the tools. Therefore, the understanding of bolt joint characteristics is essential for improving machine design and assembly. Firstly, According to the experimental data obtained from the experiment, the stiffness curve formula was fitted. Secondly, a finite element model of unit bolt joints such as bolt flange joints, bolt head joints, and thread joints was constructed, and lastly the stiffness parameters of joint surfaces were implemented in the model by the secondary development of ABAQUS. The finite element model of the bolt joint established by this method can simulate the contact state very well.

## 1. Introduction

Bolt joints are the main constraints in machine tools, e.g., the bolts joints between a column and a bed structure or those between a guide way and its bed. Because of their nonlinear characteristics<sup>[1]</sup>, these joints affect the static and dynamic behavior of the entire structure of a machine tool. Bolt joints consist of the joint surface of a bolt head, joint surface of a screw thread, and surface of a flange fastened by bolts. The behavior of these joint surfaces and that of bolts are connected, thus making it difficult to understand the behavior of bolt joints.

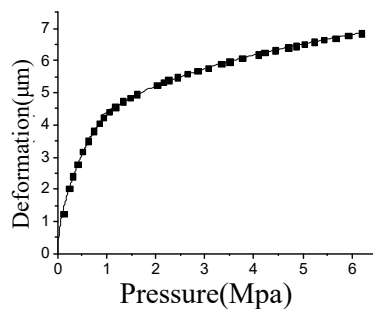
The modeling of bolt joints has been performed by many researchers, and the finite element method (FEM) is one of the main simulation methods used. Usually, a three-dimensional (3D) finite element model is necessary for analyzing laminated composite bolted joints because stress and strain vary in all directions owing to factors such as bolt bending and tilting, bolt pre-load, and secondary bending. Bibekananda Mandal et al. analyzed stress and strain regularity of bolt joints under an axial load using an FEM software and estimated the fatigue life of these joints<sup>[3-5]</sup>. Luciano Feo examined the distribution of shear stresses among different bolts by varying the number of bolt rows and bolts per row and reported that the load is not distributed equally. The latter is due to varying bolt positions, bolt-hole clearance, bolt-torque or tightening of bolts, friction among member plates, and friction at a washer-plate interface<sup>[6]</sup>. B. Egan provided a highly detailed analysis of stress distribution at the countersunk hole boundary using the nonlinear finite element code ABAQUS, including that clearance in the model was shown to result in far higher radial stresses compared to those in the neat-fit joint model, an associated loss in joint stiffness of more than 10% was recorded for the highest clearance considered (240  $\mu\text{m}$ )<sup>[7]</sup>. L. Liu found that the contact stress is concentrated in layers that are close to the shear plane, most stress components follow a cosine distribution around a fastener hole, the out-of-plane and interlaminar shear stresses are quite high in layers close to the shear plane, and stress distributions of different layers are dependent on the ply angles of a specified layer<sup>[8]</sup>.



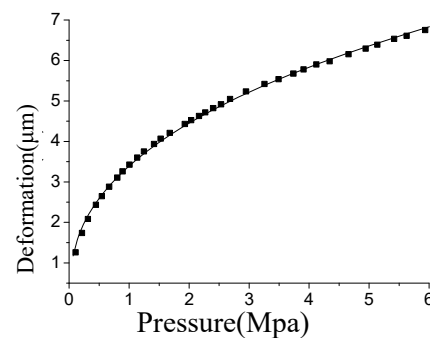
All contact properties of these models are based on software functions. Joints have many influencing factors such as load, matching materials, size, surface roughness, and processing methods. Because a finite element software cannot completely reflect the contact properties of a bolt, they cannot provide high-precision data. Thus, Firstly, According to the experimental data obtained from the experiment, the stiffness curve formula was fitted. Secondly, a finite element model of unit bolt joints such as bolt flange joints, bolt head joints, and thread joints was constructed, and lastly the stiffness parameters of joint surfaces were implemented in the model by the secondary development of ABAQUS. All this provides a basis for the design and accurate modeling of bolt joints.

## 2. Static stiffness parameter test of unit joint surface

We can perform normal contact characteristic test of matching materials commonly used in the bolt joints of a machine tool. Figure 1 represents the curve of the relation between the pressure and deformation of the joint surface when the materials are cast iron- cast iron and grinded-grinded. Figure 2 represents the curve of the relation between the pressure and deformation of the joint surface when the materials are 45 steel - cast iron and grinded-grinded.



**Figure 1.** HT Grinding Ra0.8—45# Grinding Ra0.8



**Figure2.** HT Grinding Ra0.4—HT Grinding Ra0.8

As can be seen from the chart, it is nonlinear under the condition of low surface pressure ( $\leq 1$ MPa), whereas it gradually changes to be linear when the pressure is above 1 MPa. Thus, the data is fitted with a piecewise function.

$$\lambda_n = \begin{cases} CP_n^m & P_n \leq 1 \text{ MPa} \\ A + BP_n & P_n > 1 \text{ MPa} \end{cases} \quad (1)$$

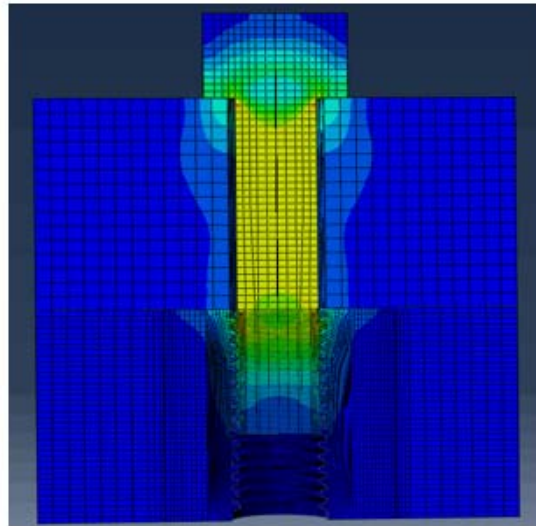
Where  $\lambda_n$  is the normal deformation of the joint,  $P_n$  is the normal surface pressure. C, m, A and B are the normal parameters of the joint surface. They are consistent with the contact pressure, the bonding surface, the lubrication, the processing method, the surface roughness Degree and other factors. These coefficients are determined experimentally. Further, we can take the derivative of pressure to obtain the law of the change of the surface stiffness per unit area with the pressure.

## 3. Finite element analysis of bolt joints

### 3.1. Finite element model of bolt joints

In order to establish an accurate model of the bolt joints, the experimental data is fitted into a stiffness curve and written to the Uinter subroutine (the secondary development program of ABAQUS). The finite element model of bolt joints is shown in Fig. 8. The 3D model of a single bolt used in the finite element analysis is established in accordance with its real dimensions to obtain more precise characteristic parameters of bolted joints. The bolt material is 45 steel and set the elastic modulus to 210Mpa, set the Poisson's ratio to 0.27, set the strength grade to 12.9 and set the yield stress to 1080Mpa. The upper and lower specimen material is HT300, set the elastic modulus to 110Mpa and

set the Poisson's ratio to 0.25. The analysis procedure in ABAQUS is to set the material properties of individual components, contact properties, analysis steps, constraints, and meshing, and the last step is to submit analysis documents. Finally, stress-strain analysis is conducted after adding the characteristic parameters of the joints to bolted joints by the secondary development program of ABAQUS. Taking an M12 bolt for example, the variation of the contact stress of bolt joints is analyzed under the condition of Specific bolt pre-loads and flange thicknesses.



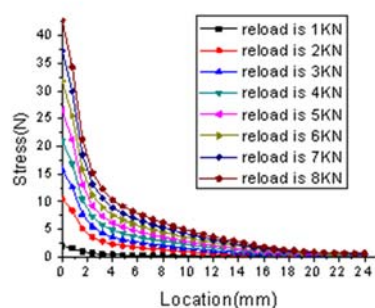
**Figure 3.** Grid model of bolt joints

3.2. *The results of the analysis of the bolted joint based on the parameters of the joint surface are compared with the ABAQUS affiliated contact analysis*

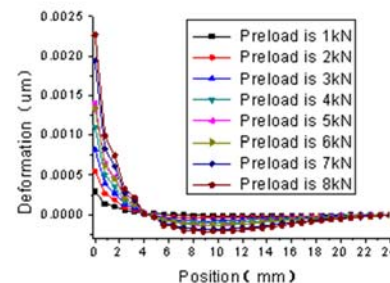
3.2.1. *Analysis Results of Bolt Joints Based on basic characteristic parameters of joint surface.* When the flange thickness is 10mm, bolt preload force are 1kn, 2kn, ..., 8kn, the stress distribution of flange-joint interface shown in Figure 4. As can be seen, the stress of the flange joint surface increases with the increase of the bolt preload force, the radial stress decreases with the trend, and the stress is relatively concentrated around the hole.

The deformation distribution of flange-joint interface shown in Figure 5. It can be seen that the stress of the flange joint surface increases with the increase of the bolt preload and the pressure gradually decreases in the radial direction.

It can be seen that the impact radius is about 5mm away from the screw hole.

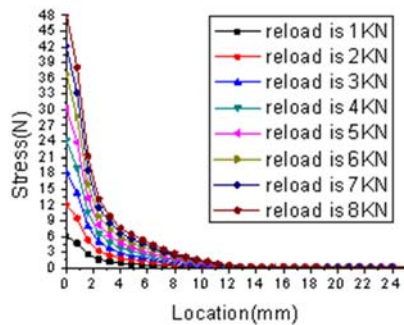


**Figure 4** Stress distribution of flange joint surface based on basic characteristic parameters of joint surface

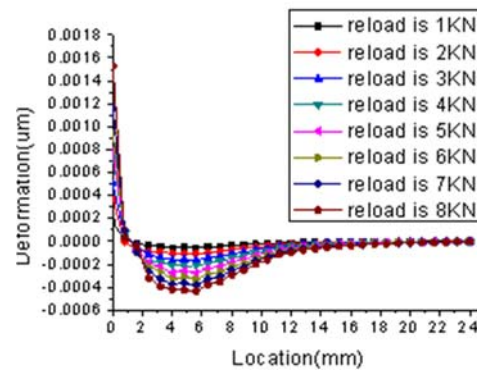


**Figure 5** Deformation distribution of flange joint surface based on basic characteristic parameters of joint surface

3.2.2. *Use the contact method of the Abaqus software tool to analyze the bolt joint.* Choose Abaqus software tool definition contact: the tangential friction coefficient of the bolt joint is defined as 0.15 and the normal contact property is "hard" contact. When the flange thickness is 10mm, bolt preload force are 1kn, 2kn... 8kn, the stress distribution shown in Figure 6. The deformation distribution shown in Figure 7.



**Figure 6** Stress distribution of flange joint surface with Abaqus tools



**Figure 7.** Deformation distribution of flange joint surface with Abaqus tools

*Comparison of the results of the two analytical methods.* It is found that the analysis result of the bolted joint model based on basic characteristic parameters of joint surface is very different from the analysis result of the Abaqus software tool. The deformation of the model of this paper is larger and the decay rate is slower. The radius of action of the bolt preload is different. It can be seen that the modelling method has a great influence on the bolted joints. The proposed method is based on the experimental data of the joint surface, so it can better reflect the law of the joint surface.

#### 4. Conclusion

This study analyzed the influence of stress and strain on an M12 bolt. A finite element model of unit bolt joints such as bolt flange joints, bolt head joints, and thread joints was constructed, and the basic characteristic parameters of joint surfaces were implemented in the model by the secondary development of ABAQUS to analyze the stress on bolt joints. The conclusions are as follows:

- (1) Under a bolt pre-tightening force, the deformation value at various points on a bolt joint along the radial direction beyond a certain distance is approximately zero, thus confirmed the size of the circular area of the action of surface pressure. This is the basis for the design of a distribution scheme of each bolt in multi-bolt joints.
- (2) There is stress concentration around the screw hole. It is important that the strength of the force decided bolt bearing.
- (3) The proposed method is based on the experimental data of the joint surface, so it can better reflect the law of the joint surface.

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