International Journal of Control and Automation
Vol.9, No.2 (2016), pp.1-8
http://dx.doi.org/10.14257/ijca.2016.9.2.01

Analysis about Static Characteristics of Machine Tool Bolted Joint Based on Virtual Medium

Ren Sheng-le*, Gao Fei, Dai Ye, Wang Peng and Cheng Tian-yu

School of Mechanical & Power Engineering, Harbin University of Science and Technology, Heilongjiang Harbin 150080, China
**renshengle@163.com*

Abstract

The Department of Heavy NC machine tool is a complex structure. The working performance of the machine has the very big impact. The machine tool of influence is very important. In this paper the bolt combined with sub structure of Heavy NC machine tool as the research object, the. In conjunction with the Ministry of the virtual medium dynamics model method to establish the combination of fixed bolt. In this paper the bolt joint of Heavy NC machine tool as the research object. Combination of bolts binding kinetics model is established by using the virtual medium method The parameters change the dynamics of model, the influence of bolt pretightening force, tool materials and processing, has been part of the characteristics and rule of machine tool joint.

Keywords*: characteristic analysis; virtual media; modal analysis; bolt joints*

1. Introduction

The mechanical structure of the whole machine is composed of various parts or by a combination of the functional requirements [1]. We call the combination of parts of the site with the department. No matter what kind of combination, the combination of both belongs to the "flexible combination". The stiffness is often an important part of the overall stiffness of the mechanical structure, and sometimes even become the weak link of the whole stiffness.

According to the mechanical basic characteristic parameters of joint surface provide a general form, it can be divided into three categories [2]: per unit area, the basic unit parameters and parameters of typical unit parameter.

According to the influence of many factors, complex, so the needs for these factors combined with the characteristic were analyzed, classified, and then make the appropriate treatment [3]. Considering the factors influencing the characteristics of the flexible joint, which is nonlinear. The first category is related to factors such as the structure and, in conjunction with the Department of the type, size and shape. The second category is related to the factors and conditions, such as pressure, state, combined with the vibration frequency, the joint surface between the media. The third category is combined with the inherent characteristics of the relevant factors, such as dealing with the material, thermal state, processing method and surface roughness.

2. Theoretical Study on Joint Surface

Virtual media method is the combination of surface of heavy machine is equivalent to a layer of virtual material. This material is imaginary, does not exist. We assume that the virtual layer with elastic modulus, Poisson's ratio and density [4]. The CNC machine tools with components of the material can be measured can also look up table. The influence factors of pre tightening force, machine combined with surface deformation will occur, but the material parameters of the original machine tool have no longer used. Now is not a

ISSN: 2005-4297 IJCA

good experimental scheme to obtain the parameters of surface, so need to contact theory the new formula, calculate the virtual medium elastic modulus, Poisson's ratio and density. Combined with the contact part of the stiffness and damping is not easily measured in the experiment, the method of modeling the advantage is not for them to complete the prototype simulation.

The establishment of machine tools in the ANSYS Workbench combined with dynamic model, need to bolt, nut, washer is added to the model, with a bolt hole sealing part, according to the model of the characteristic [5], the upper and lower two machine tool assembly and virtual layer by way of eight node hexahedron mesh, figure 1 is the virtual medium method the establishment of the model.

The virtual layer in the middle position of components, to the edge of the hole mesh refinement, better with the Department under the loading stress and deformation.

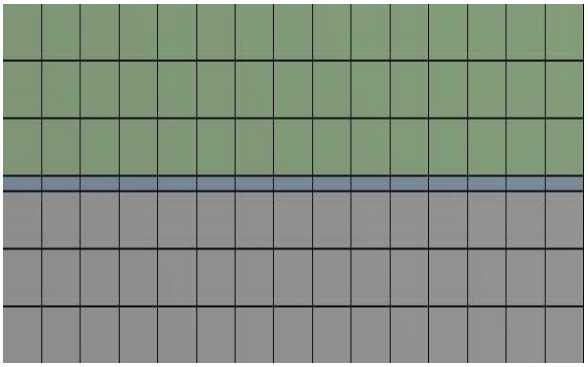

Figure 1. Combined with the Virtual Material Method Modeling

Modal analysis of virtual property that the material elastic modulus, Poisson's ratio and density of virtual material properties, characteristics of virtual material available theoretical formula are derived as follows[6]

$$E = \frac{2D\psi^{1-0.5D}}{3\pi^2} E^* G^{D-1} a_L^{0.5D} \left(a_c^{-0.5} - a_L^{-0.5} \right) \quad (1)$$

$$\mu = \frac{\left(1+\mu'\right) E^*}{G_x^*} - 1 \quad (2)$$

$$\rho = \frac{\rho_1 h_1 + \rho_2 h_1}{2h_1} = \frac{\rho_1 + \rho_2}{2} \quad (3)$$

In the formula., D is the fractal dimension, ψ is determined by the fractal dimension parameter; E^* is the equivalent elastic modulus; G^{D-1} fractal characteristic length scale; a_L is the largest area of micro convex body contact; a_c is micro convex body contact area, μ' is the equivalent Poisson's ratio; elastic modulus; G_x^* is a dimensionless quantity of virtual material, ρ_1 and ρ_2 are the density of the material, h_1 and h_2 are the thickness of the entity.

3. Combined with the Dynamic Modeling

The structure of machine tool to determine the design needs [7]. Considering the combination of the characteristics of the test piece, can fully display the mode shapes of

the case, try to simplify the model. According to the practical observation, machine bolt joints are arranged is linear. So, choose a linear representation of the three bolts for experiment, the specimen material for steel Q235 (elastic modulus E=212Gpa, Poisson ratio is =0.288, the density of =7860kg/m3). The surface roughness Ra value is 0.8. The process is grinding, size is 200×100×12mm, and connected by three M16 bolts. The specimen is shown in Figure 1 in the experiment.

General screw bolt and nut is not required to draw, but also need to follow some analysis work, and in order to better study on machine tool with contacts, the bolt and nut thread drawing, assembly drawing of the Pro/E model is shown in figure 2.

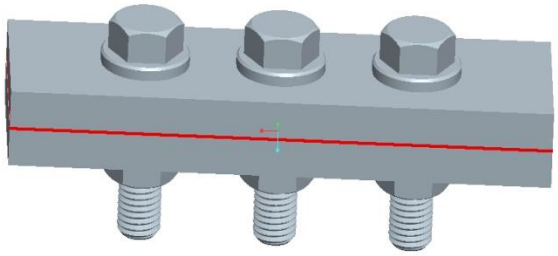

Figure 2. The Assembly Model

According to the model size, elastic modulus $E_1=E_2=212GPa$, Poisson's ratio is $\mu_1=\mu_2=0.288$, density is $\rho_1=\rho_2=7860kg/m3$, surface roughness is $Ra_1=Ra_2=0.8\mu m$. The ultimate combination of virtual media elastic modulus E=0.631GPa and Poisson's ratio $\mu=0.28$.

The machine combined with theoretical model and real experimental results have a certain error. But from the obtained results, the error value is stable, and the two trends of the result are the same. According to the relative error formula

$$\varepsilon = \frac{|\Delta x_1|}{x_0} \times 100\% = \frac{|x_1 - x_0|}{x_0} \times 100\% \qquad (22)$$

The results obtained from the test is the true value of ANSYS, the calculation result of Workbench belongs to the theoretical analysis, so the former should be set to x_0, which is x_1, the calculated results are shown in table 1.

Table 1. Modal Results Comparison and Error Ratio

Steps	1	2	3	4	5
The test frequency (Hz)	2059.6	3633.9	4574.2	4782.1	7127.4
Simulation of frequency (Hz)	2193.1	3870.1	4843.1	5099.6	7520.2
Error ratio %	6.48	6.50	5.89	6.64	5.51

The two groups of data input to the MATLAB, contrast map is obtained as shown in figure 3.

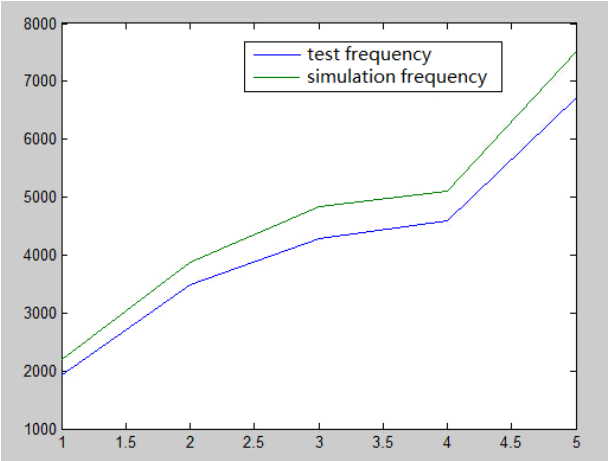

Figure 3. Comparison of Theoretical and Experimental Frequency

Can see from the table 1, the total error of simulation test frequency and frequency average percentage was 5.51%~6.64%, the frequency in the same trend.

Analysis of shortcomings of existing modeling methods, put forward a virtual media based method to establish the dynamics model of bolt combined machine tool, elastic modulus, Poisson ratio of the medium, the density of the virtual stress calculation of point contact with arbitrary, after repeated experiments and subsequent research, the related calculation formula to calculate the as the establishment of dynamic model for machine tool. As a tool of bolted joint influence factors study pave the way.

Through the ANSYS Workbench simulation model is established combined with the bolt, and get the first five order natural frequency, compared with the natural frequency of the experiment, the dynamics simulation model established is accurate and reliable.

Tightening torque machine bolt is generally maintained at 30 $N \cdot \mathrm{m}$ -90 $N \cdot \mathrm{m}$ [8]. In the process of bolt tightening force, more complex, bolts and connecting components will be deformed. The torque is not so simple clamping force. According to the formula of calculating parameters, the parameters of the virtual HT250 gray cast iron materials of different bolt tightening torque conditions. The specific parameters are shown in table 2.

Table 2. Parameters of the Virtual Material under Different Preload

T/ $N \cdot \mathrm{m}$	E/GPa	μ	ρ
30	0.631	0.22	7340
45	0.671	0.23	7340
60	0.736	0.24	7340
90	1.41	0.27	7340

The majority of Heavy NC machine tool with the material is HT150, HT200, HT250 and HT300 [9]. According to the calculation formula of the virtual medium, the bolt preload is 90 under the condition of different materials, parameters of the virtual medium is shown in table 3, due to the Poisson properties of HT200 materials is higher than that of other materials.

Table 3. Parameters of the Virtual Material under Different Material

Material Science	E/GPa	μ	ρ
HT150	90	0.25	7000
HT200	100	0.3	7200
HT250	116	0.27	7340
HT300	130	0.25	7500

Combined with the characteristics of the shape parameters and the surface has the very big relations, different processing methods of combining surface has great influence. The method is commonly used in the processing of mechanical parts with milling, finish turning and grinding, the three kinds of the surface roughness values are 3.2, 1.6 and 0.8. The machining accuracy is low, the rough surface, the machine tool surface asperity peak is higher, the corresponding virtual medium thickness should be increased. After examining the surface roughness measurement experiment of relevant information, the virtual milling medium thickness corresponding to the set to 1.4mm, the virtual media thickness and fine machining of the corresponding set to 1.2mm.

4. Study on the Influence Factors

The finite element model of the parameters after the input, to mesh the model, the model unit, which is easy to solve, the mesh quality has great influence on the results, the mesh model's precision is high, the natural frequency results more close to the real value. At the same time, the solution will be a long time. The combination of surface and upper and lower plate is defined as the rough contact between the steel plate and bolts, washers; nuts, defined as the binding contact. For the three-dimensional geometry, ANSYS Workbench has several different meshing methods. The combination of machine tool model with the free mesh division is completed, the model shown in figure 4.

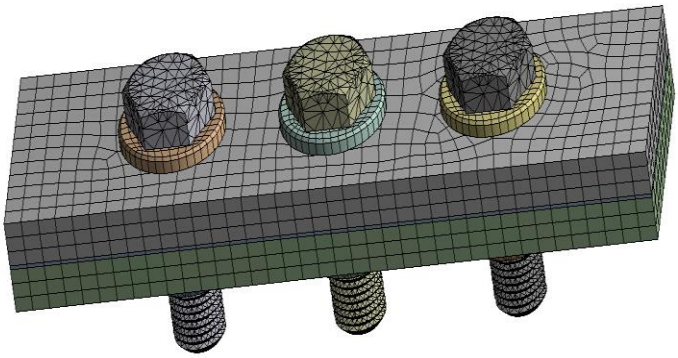

Figure 4. Model after Mesh

Under constant load stress under the action of the model, the natural frequencies and mode shapes can be changed. Reflect the structure of the effect on the size of a small number, the thinner the more obvious. Therefore, combined with the effect of bolt using software to do the modal analysis to consider when pretightening force [10].

Prestressed modal analysis needs to consider the interaction and mutual influence of static and modal. Coupling analysis of the first two will be applied to the static model, and then according to the process of modal analysis.

The new Workbench in a modal analysis, coupled with the finite element software analysis and the static analysis associated with it, so that the structure can achieve data sharing, and then follow the normal steps modal analysis. The parameters of the virtual medium under different bolt tightening torque were input into the ANSYS Workbench solution, the obtained results are shown in table 4.

Table 4. Different Bolt Pretightening Force for the First Five Steps Natural Frequency

steps / Pretightening force	1	2	3	4	5
30	1604.2	2838.6	3732.8	3740.6	5588.5
45	1610.4	2849.3	3733.3	3755	5607.2
60	1620.5	2866.9	3734.1	3778.7	5637.9
90	1706.7	3021.2	3741.3	3991.5	5911.4

The parameters of the virtual machine under different media materials are input into the ANSYS Workbench to carry on the analysis, the first five order solution results are shown in table 5.

Table 5. First Five Steps Natural Frequencies of Different Materials

steps / Material Science	1	2	3	4	5
HT150	1541.1	2744.3	3376.4	3612.7	5370.3
HT200	1601.6	2816.2	3494.7	3747.5	5519.3
HT250	1620.5	2866.9	3734.1	3778.7	5637.9
HT300	1786.6	3177	3931	4176.2	6208.7

The new models are established in Pro/E and complete the analysis. We get the HT300 gray cast iron in the pre tightening force for the modal analysis result of the 90. As shown in table 6.

Table 6. Different Roughness of the First Five Order Natural Frequency

steps / Roughness	1	2	3	4	5
Ra3.2	1782	3082	3900	4111.5	5526.8
Ra1.6	1812.2	3133.7	3917.8	4185.6	5590.3
Ra0.8	1786.6	3177	3931	4176.2	6208.7

5. Conclusion

As can be seen from table 3, the bolt tightening torque to a certain extent affected the machine combination. The bolt tightening torque is bigger, the CNC machine tools combined with the modal frequency is greater. The trend of increase exponentially, also shows that the virtual medium stiffness values increased.

From table 4, the choice of different materials on the combination of machine tool has a great influence. The machine with natural frequency increases from HT150 to HT300. The modal characteristics are similar. The stiffness, modal frequency of virtual medium is increased with the increase of material stiffness value.

As can be seen from table 5, the first fourth order natural frequency, precision machining is higher than that of milling and grinding. But machining fine car second, third, fifth order natural frequency and less grinding. Therefore, the roughness effects are complex to impact combination of machine tool.

Acknowledgements

Thanks to the Education Department of Heilongjiang province science and technology project of Longmen heavy duty machine tool crossbeam mechanism and optimal process parameters for ship intelligent pipe (12531124) for the financial support.

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