The Modeling Methods of Heavy NC Machine Tool Bolt Joint Based on Virtual Media

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Abstract

The Department of Heavy NC machine tool has a great influence on the performance of machine tools. The 30%-50% static stiffness, more than 50% of the dynamic stiffness depends on the combining part, and the influence on damping reached 90%.Machine tool with the Department of static and dynamic performance directly determines the accuracy and reliability of Heavy NC machine tool. Therefore, in conjunction with the Department of research and design of Heavy NC machine tool is very important. In this paper, based on Hertz contact theory, the contact at the micro level, considering the combination form of machine tool, and the machine joints as a virtual media simulation, a combination of virtual media framework, and calculation of characteristic parameters of the virtual material, then use the ANSYS Workbench to solve the combination of the natural frequency of the whole, the first five order modal extraction. Using modal test technology, get the specimens of natural frequency and damping of the true value, natural frequency are compared with theory, prove the formula of virtual media is reliable, can be used in the modeling of heavy machine tool.

Keywords: junction surface, contact theory, modal analysis, virtual materials

1. Introduction

CNC machine tools have many parts and a combination part. Because of the large number of include flexible joint, so in addition to the properties in addition to affected parts characteristics, but is also greatly affected by the combination of characteristics. The dynamic characteristics of joints affected by many complicated factors, which makes the research of complicated. Research shows that the Department has a great impact on the overall performance of the machine tool [1]. Because it is difficult to identify with the dynamic characteristics under different working conditions, so how to establish accurate dynamic model of machine tool has become a major problem for the modeling.

Combining between the parts is caused by discontinuous machine, the machine more than 50% stiffness and damping from the combination of 90% or more [2]. Therefore, combined with the identification, modeling and solving the parameters of static, dynamic characteristics of machine tool is an important foundation of the research and structure optimization problem.

Combined with the dynamic characteristics of the Ministry it is nonlinear, and the combinations of conditions are different, so the combination treatment is more complex [3]. The dynamic simulation is to develop a virtual prototype model of design scheme, and the performance prediction and detection. By adjusting the design scheme of machine tool design, get the best design, so as to achieve the processing and transformation of the whole machine. But due to the significant influence of the machine tool, so the combination of dynamic modeling and Simulation of the influence of machine tool modeling will become one of the most important aspects.

2. Study on the Theory of Virtual Medium

Machine tool combination is essentially composed of 2 rough surfaces [4]. The actual surface roughness peak shape is usually ellipsoid. So the rough peak can be approximated as a sphere, in conjunction with the Ministry of machine can be simplified as a series of uneven spheres touch each other.

The machine surface peak is irregular distribution, contact is irregular, so must seek common points of contact to meet every situation. By using the least square method, the average line can be obtained with the Department, the function value and the minimum difference.

$$M = \sum_{i=0}^{7} \left[y_i - (at_i + b) \right]^2 \tag{1}$$

The machine with the same and the micro convex body is normal distribution, according to the Gauss formula can be calculated asperity height distribution probability, the mathematical expression

$$f(x) = \frac{1}{\sqrt{2\pi}\sigma} \exp\left(-\frac{(x-\mu)^2}{2\sigma^2} \right) \tag{2}$$

Among them, μ is the mathematical expectation, σ is variance. Type 1 is relative to the zero line somewhere on the surface deformation of the height, length of 2 is selected. According to the statistics can get the formula of probability density.

$$\phi(z) = \frac{1}{2} - \frac{1}{(2\pi)^{1/2}} \int_0^{z/\sigma} \exp\left(-z'^2/2\sigma^2 \right) d\left(z'/\sigma \right) \tag{3}$$

The displacement depends on the contact surface of the contact pressure distribution [5]. Therefore, in order to achieve a given arbitrary shaped objects in contact point pressure, there is a need for a pressure integral equation. If the object with a Winkler based simulation model, can avoid this problem.

Shear between adjacent cell models ignore the basis. δ on behalf of the press in origin, is the basis of the method to the elastic displacement

$$\overline{u}_z(x,\ y) = \begin{cases} \delta - z(x,\ y), & \delta > z \\ 0, & \delta \leq z \end{cases} \tag{4}$$

The size and direction of the displacement of a point on the model is directly decided by the point of the pressure, and then draw

$$p(x,\ y) = (K/h)\overline{u}_z(x,\ y) \tag{5}$$

In the formula K is the modulus of elasticity of foundation. Face to face contact, the contact part can be regarded as the two hemispheres, their curvature can be set to R1 and R2, and the variable Z (x, y) satisfies elliptic equation. Therefore, within the contact area can be written

$$\overline{u}_z = \delta - \left(x^2 / 2R^1 \right) - \left(y^2 / 2R^2 \right) \tag{6}$$

The model does not contact the part $\overline{u}_z = 0$, The contour is close to an ellipse, contact pressure

$$p(x,\ y) = (K\delta/h)\left\{ 1 - \left(x^2/a^2 \right) - \left(y^2/b^2 \right) \right\} \tag{7}$$

By means of integral, total load

$$P = \frac{K\pi ab\delta}{2h} \tag{8}$$

The machine combined with surface contact area has small deformation. Contact surface is oval. The contact part of the machine by the surface stress does not exceed the elastic limit. The contact area is much smaller than the surface area of the machine tool. The radius of contact is $a = \sqrt{Rd}$. Hertz contact stress requirements of the object can be regarded as the hemisphere with deformability. The contact surface is only the vertical distribution of pressure [6]. Hemisphere Hertz stress method to load

$$\overline{P} = \frac{4}{3} E^* \sqrt{R_p} d^{3/2} \tag{9}$$

In the formula, E^* is combined with rough surface corresponding, R_p is the radius of curvature of two rough surfaces of the corresponding.

$$\frac{1}{E^*} = \frac{1-\mu_1^2}{E_1} + \frac{1-\mu_2^2}{E_2} \tag{10}$$

In the formula, E1, E2 are respectively the elastic modulus. μ1, μ2 is the Poisson's ratio. If given two spheres of radius R1 and R2, R was defined as

$$\frac{1}{R} = \frac{1}{R^1} + \frac{1}{R^2} \tag{11}$$

Then the contact area pressure distribution

$$P = P_0 \left(1 - \frac{r^2}{a^2} \right)^{\frac{1}{2}} \tag{12}$$

After calculation, the elastic modulus formula can be obtained for the virtual medium

$$E = \frac{2D\psi^{1-0.5D}}{3\pi^2} E^* G^{D-1} a_L^{0.5D} \left(a_c^{-0.5} - a_L^{-0.5} \right) \tag{13}$$

Poisson's ratio is an important parameter in the intrinsic properties of materials. According to the material being produced by the strain of tensile or compressive stress, Poisson's ratio of subdivision based Poisson's ratio and Poisson's ratio. In the two-dimensional coordinates than generally refers to the main Poisson. Load X axe make the Y axis strain. Poisson's ratio is Y times the load axis on the X axis changes. Machine tool on the surface belong to the same kind of engineering materials, so we think that the middle of the virtual media Poisson's ratio is similar to the direction of. After calculation, the Poisson's ratio of the virtual medium

$$\mu = \frac{(1+\mu')E^*}{G_x^*} - 1 \tag{14}$$

Machine tool with two joint surface asperity contacts embedded. Therefore, it can be regarded as a composite material.

$$\rho = \frac{m_1 + m_2}{V_1 + V_2} = \frac{\rho_1 V_1 + \rho_2 V_2}{A h_1 + A h_2} = \frac{\rho_1 A h_1 + \rho_2 A h_2}{A h_1 + A h_2} = \frac{\rho_1 h_1 + \rho_2 h_2}{h_1 + h_2} \tag{15}$$

In the formula, M1, M2 is the quality of machine tool with surface occupies in the virtual medium layer, while V1, V2 is the two dielectric layer surface occupies in the virtual volume. P1, P2 is the density of the material. H1, H2 is the virtual material height, the height is not easy to measure, and the two material with the same roughness, density of virtual material formula.

$$\rho = \frac{\rho_1 h + \rho_2 h_1}{2h_1} = \frac{\rho_1 + \rho_2}{2} \tag{16}$$

3. Dynamic Modeling and Experimental Study on Surface Characteristics

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 Figure1 in the experiment.

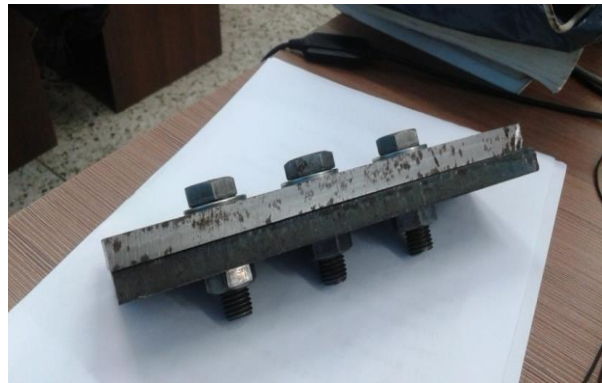**Figure 1. Experimental Specimens with Bolted Joint**

According to the model size, elastic modulus E1=E2=212GPa, Poisson's ratio is μ1=μ2=0.288, density is ρ1=ρ2=7860kg/m3, surface roughness is Ra1=Ra2=0.8μm.

The equivalent elastic modulus for

$$E' = \frac{E_1}{2\left(1 - \mu_1^2\right)} = \frac{212}{2\left(1 - 0.288^2\right)} = 115.6\,\text{Gpa} \tag{17}$$

Combined with the equivalent shear modulus for

$$G' = \frac{G}{2\left(2 - \mu_1\right)} = \frac{E_1}{4\left(2 - \mu_1\right)\left(1 + \mu_1\right)} = 24GPa \tag{18}$$

The equivalent Poisson's ratio

$$\mu' = \frac{E'}{2G'} - 1 = \frac{2 - \mu_1}{1 - \mu_1} - 1 = \frac{1}{1 - 0.288} = 1.4 \tag{19}$$

According to the virtual medium formula for solving equations, combined the virtual medium elastic modulus E=0.631GPa and Poisson's ratio μ=0.28.

In the establishment of machine tool of bolted joint, three-dimensional software used is Pro/ENGINEER. Will be drawn by the Pro/E model into a IGS file, and then import the ANSYS Workbench.
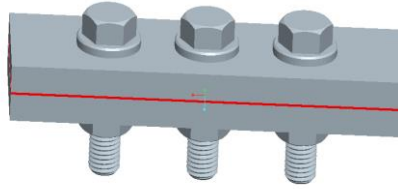

Figure 2. The Assembly Model

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, the bolt joints need analysis in the modal influence of preload consideration [8]. The pre tightening force modal analysis needs to consider the interaction and mutual influence of static and modal. The first will be applied to the static model, and then according to the process of modal analysis.

Pre stressed analysis calculation formula is as follows

$$[K]\{x\} = \{F\} \tag{20}$$

The stress stiffness matrix is used to calculate the structural analysis. So that the original can be modified for the modal equation

$$([K] - \omega_i^2 [M])\{\phi_i\} = 0 \tag{21}$$

Pre tightening force is applied to the rod part of the bolt, 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 modal analysis procedures can be[9]. Both the static analysis and modal analysis are applied to the boundary conditions for the model, in order to show the mode better, decided to choose the combination of fixed at both ends, the whole deformation is obtained by solving the model calculation.

The new Workbench in a modal analysis, coupled with the finite element software analysis and the static analysis associated with it [10], so that the structure can achieve data sharing, and then follow the normal modal analysis procedures can be. After solving the natural frequencies and mode shapes are shown in Table 1.

Table 1. Results of the First Five Order Model

Steps	1	2	3	4	5
Natural frequency (Hz)	2193.1	3870.1	4843.1	5099.6	7520.2

After the end of modal analysis, to enter into the after treatment, after treatment can be viewed through the operation of each mode, the first five modes as shown in figure 3.
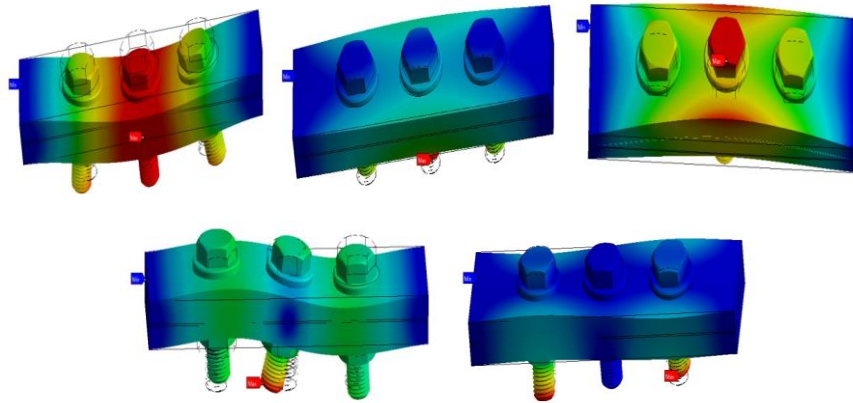
Figure 3. First Five Order Modal Shape

The original shape model by grey wire frame representation, we can see the model structure has changed a lot. A modal of the maximum deformation with central, two orders and four order in the middle of the bottom screw bolt position, in the middle of three order and five order in the bolt head, on both sides of the bottom bolt.

In modal analysis, each mode has the sample and the corresponding natural frequencies and mode shapes, the natural frequency is the governing equation of the characteristic value, and the modal is the equation of the feature vector, which is the key parameter to find the modal test, parameter identification method, can calculate these parameters in the response frequency.

In this experiment, the guide is divided into 36 excitation and three blows and collect the data of each point of hammer excitation. The system automatically data linear average, and finally the data import all the excitation point analysis software.

Matching the calculated data to the model, and then automatically interpolated by the combination of a test mode. The natural frequency and damping calculation function to find the combination of machine tool by using the peak search and the parameters of the software, the results obtained are shown in table 2.

Table 2. The First Five Steps of Natural Frequency with the Model

Steps	1	2	3	4	5
Natural frequency (Hz)	2059.6	3633.9	4574.2	4782.1	7127.4
Damping ratio （%）	1.17	1.38	1.09	1.21	1.37

4. Theoretical and Experimental Comparison

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 3.

Table 3. 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 4.
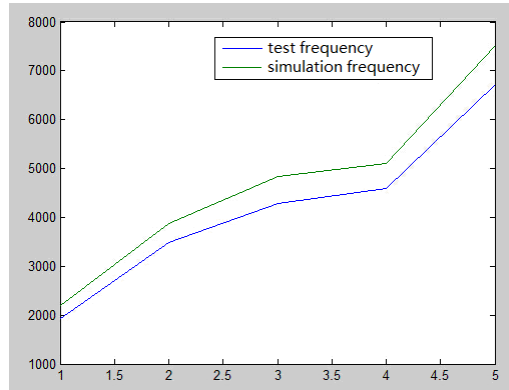

Figure 4. Comparison of Theoretical and Experimental Frequency

Can see from the table 4, the total error of simulation test frequency and frequency average percentage was 5.51%~6.64%, the frequency in the same trend.

5. Conclusion

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.

Acknowledgements

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