The Static Characteristic Analysis on Key Components of Boring-milling Machining Center

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Abstract. Taking TH5650X50 Boring-milling Machining Center as the research object, analyze the static characteristics of the two key components of the milling system. Use finite element software to create 3D model of the two key components of the milling system and design the whole virtual assembly of milling system. Based on the theory of cutting deformation, consider the application of its forces and non-forces in the way of a remote payload and remote quality. The finite element model of spindle box-principle axis and crossbeam are obtained by circular grid division method, and all the parameters of the finite element model are solved by FFEPPlus solver in Solidworks Simulation module. The study verifies the accuracy of the finite element mode, and obtains the deformation of the two key components under the most adverse conditions.

Key words: Boring-milling machining center, Key components, Static structural analysis, Finite element analysis, Solidworks.

1. Introduction

As the continuous improvement of machining accuracy of machine tools, the technology development of boring-milling machining center has gradually obtained the characteristics of intelligence, high speed, precision, modularization and complexity [1-2]. The static and dynamic characteristics of machine tools are important factors affecting the machining accuracy and stability of the equipment. Therefore, it is problem demanding prompt solution to analyze the static and dynamic characteristics and explore measures to improve them[3-5].

In this paper, static characteristic analysis was carried out for spindle box and crossbeam, two key components of boring-milling center milling system, using Solidworks software. A series of useful conclusions were obtained through the establishment of finite element model and the analysis of the static comprehensive displacement, which laid a foundation for the of the whole structure’s dynamic characteristic analysis and the whole machine’s optimization design and electromechanical simulation.

2. Whole structure

As shown in Fig. 1, TH5650X50 boring-milling machining center includes two spindles of boring spindle and milling spindle, with the structural characteristics of both boring machines and milling machines. For the processing of large complex box parts, the boring, milling, drilling and other
processing procedures on multiple surfaces of the parts can be completed after one clamping, which effectively avoids the problem of accuracy decline caused by multiple clamping.

![TH5650X50 boring-milling center model](image)

1. Bed 2. Milling pillar 3. Crossbeam 4. Milling slide table 5. Spindle box 6. Boring pillar 7. Boring slide table 8. Ram 9. Workbench

**Fig. 1** TH5650X50 boring-milling center model

3. FEA parametric modeling

3.1. Definition of material properties

For TH5650X50 boring-milling machining center, spindle box-principle axis is made of gray cast iron HT250 and crossbeam is made of gray cast iron HT300. The characteristic parameters of each material are shown in table 1.

| Materials | Elasticity modulus(GPa) | Density(kg/m³) | Poisson ratio |
|-----------|-------------------------|----------------|--------------|
| HT250     | 135                     | 7350           | 0.23         |
| HT300     | 157                     | 7800           | 0.28         |

3.2. Load and constraint

(1) Determination of cutting force

From the perspective of mechanical manufacturing process, the boring process of cemented carbide tools can be divided into two main processes of rough machining and finish machining[6]. By analyzing the values of various parameters under rough milling and finish milling conditions, it can be seen that the machining accuracy of boring is negatively correlated with its power, and positively correlated with its boring speed[7-8]. Therefore, the total milling force should decrease with the increase of machining accuracy. In order to ensure the accuracy of the analysis results, the cutting force under rough milling condition is selected as the nonpotential force affected by the components in the static simulation analysis of key components.

(2) Application of loads and constraints

After analysis, when spindle box was in the lower limit position, its displacement reached the maximum. At this time, the six surfaces in contact with the guide and the slide table should be fully fixed; the nut of the driving screw on the spindle box was fully fixed on the slide table. In addition, the gravity of the spindle box was balanced by the hydraulic cylinder fixed on the slide table, so the influence of its gravity could be ignored in the analysis. The effect of the cutting force on the spindle box was applied to the lower end surface of the spindle box and to the two ring surfaces that are in contact with the motorized spindle through a remote load.

In the analysis of the crossbeam, because the four faces in the negative direction of the Z axis of the crossbeam were all fixed on the two stand columns with bolts during installation, the four faces in the
negative direction of the Z axis of the crossbeam were subject to the fully fixed constraint. On behalf of the force of gravity on it, the gravitational field applied to the entire crossbeam was applied to the six contact surfaces between the slide table and the guide rail on the crossbeam through a remote load; finally, the milling force received by the milling cutter was also applied to the six contact surfaces between the slide table and the rail through a remote load.

3.3. Establishment of finite element model

Finite element grid division was carried out for spindle box and crossbeam in Solidworks Simulation module [9-10]. A more reasonable grid accuracy was obtained using the cyclic grid division method. In other words, the element size was set in advance according to the size of finite element model. After solving a set of results, the element size was reduced to half of the previous size for calculation; if the difference between the two calculated results was less than 5%, the previous element size was selected; if the difference between two results was greater than 5%, the element size was reduced continuously until a satisfactory result was obtained. Finite element model of spindle box and crossbeam is shown in Fig. 2-3.

4. Static characteristics analysis of key components

The finite element models of spindle box-principle axis and crossbeam were solved using FFEPlus solver in Solidworks Simulation module to obtain their comprehensive deformation and their displacement and deformation along the X, Y and Z directions, as shown in Fig. 4-5.

According to the analysis of Fig. 4, under the influence of cutting force, the maximum displacement of the spindle appears at the lower end of the spindle box, with a value of 1.189×10⁻² mm; the maximum displacement of the spindle box in the X-axis direction appears at the lower end of the spindle box, with a value of 9.462×10⁻³ mm; the maximum displacement of the spindle box in the Y-axis direction appears at the lower end of the spindle box, with a value of 7.869×10⁻³ mm; the maximum displacement of the spindle box in the z-axis direction appears at the lower end of the spindle box, with a value of 1.986×10⁻³ mm.

According to the analysis of Fig. 5, under the influence of the total force, the maximum displacement of the crossbeam appears in the middle of the crossbeam, with a value of 1.853×10⁻² mm; the maximum
displacement of the crossbeam in the X-axis direction appears in the middle of the crossbeam, with a value of $1.180 \times 10^{-2}$mm; the maximum displacement of the crossbeam in the Y-axis direction appears in the middle section between the middle and end of the crossbeam, with a value of $2.846 \times 10^{-3}$mm; the maximum displacement of the crossbeam in the z-axis direction appears in the middle of the crossbeam, with a value of $1.612 \times 10^{-2}$mm.

![Deformation nephogram of spindle box in each direction](image)

**Fig. 4** Deformation nephogram of spindle box in each direction
5. Conclusion

The spindle box-principle axis and crossbeam of TH5650X50 boring-milling center milling system were taken as the research object, and the application of the force and non-force load of the two key components was considered in the way of remote load and remote mass, and the static and static finite element analysis were conducted on them in turn. Finally, finite element analysis data of spindle box-principle axis and crossbeam, and the following main conclusions were obtained:

1) The finite element model and various parameters of spindle box-principle axis and crossbeam were obtained by the cyclic grid division method, and the above finite element model was calculated using FFEPlus solver in Solidworks Simulation module, so as to obtain its static comprehensive displacement. The remote load method, remote mass method and cyclic grid method in the simulation process can provide feasible approaches for the analysis of similar problems.

2) Whether the design of various component meets its accuracy requirements was verified using the static comprehensive displacement results. The results show that the comprehensive displacement deformation of milling crossbeam is the largest. Under the influence of gravity and cutting force, the maximum displacement of the crossbeam appears in the middle of the crossbeam, with a value of $1.853 \times 10^{-2}$mm. The comprehensive displacement does not exceed $2.0 \times 10^{-2}$mm, meeting the requirement of TH5650X50 boring-milling center that the static displacement error of various key part should not exceed 20 $\mu$m.
(3) By performing the statics analysis on the key parts of TH5650X50 boring-milling machining center, the research lays a foundation for the dynamic characteristic analysis and rigidity analysis of the milling system, which is of great significance for the subsequent electromechanical joint simulation and modeling of the whole machine.

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