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The Method for optimizing the bed structure of 5-axis machine tools

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Abstract

The five-axis vertical machining machine bed is the key component of a five-axis vertical machining center. Most of the important parts of the machine are directly mounted on the machine bed, and its static and dynamic performance directly affects the machining accuracy of the whole machine. In order to improve the static and dynamic performance of the five-axis vertical machining center bed, the bed was optimized using a structural bionics approach by combining the conformation laws of various biological structures. Firstly, finite element analysis was performed on the prototype bed, and the rib structure of the curved bed was determined based on the comprehensive deformation cloud and the conformational characteristics of the biological structure, and the bionic optimized bed was analyzed. The results show that compared with the original bed, the maximum deformation of the optimized bed is improved by 53%, the first fourth-order inherent frequency is improved, and the static and dynamic performance is significantly improved.

Keywords

Five axis vertical machining center, Finite element, Optimal design.

1. Introduction

In recent years, with the rapid, stable and sustainable development of the aerospace industry, the aerospace industry and the automotive industry, the technical parameters of the processing technology speed, feed rate, processing efficiency,, machining process processing accuracy and CNC machine tool technology and equipment operational stability, as well as the level of reliability of the operational technology performance, have put forward higher requirements [1]. At the current stage of historical development, precision CNC machine tool technology and equipment in the automotive industry, aerospace industry, shipbuilding industry, transportation industry and other areas of large box precision parts processing activities have sufficient application space, energy and military industries and disc precision parts processing activities [2]. The actual selection and application of appropriate methods to improve and optimize the basic technical performance of the internal components of precision CNC machine tool equipment will help: improve the competitiveness of the market sales of precision CNC machine tool equipment products and give full play to the best application value of precision CNC machine tool equipment [3].

2. Finite element analysis of the bed

2.1. Introduction of bed force

The machine is mainly divided into two beds, the upper bed and the lower bed are fixed by bolts, and the upper bed is subjected to the force by the XYZ axis self-weight, superimposed on the 16,500N, through the error space distribution diagram can be seen, when the Y-axis movement of the front position, at this time caused by the largest error. Therefore, by importing ANSYS analysis, the load conditions at this time are used, the specific force diagram is shown in Figure 1.

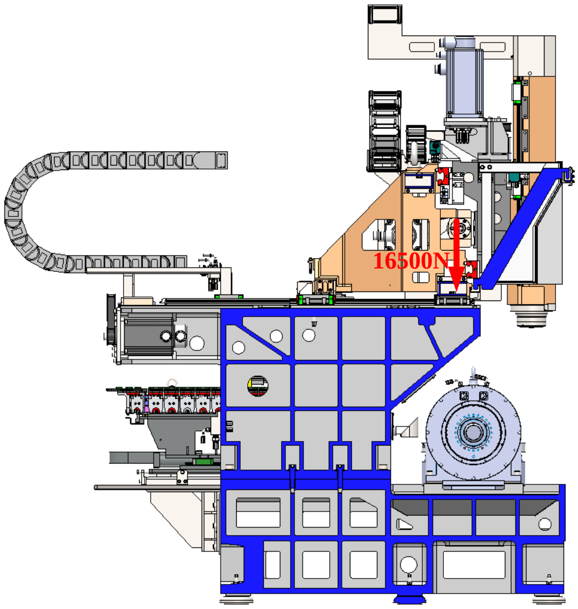

Figure 1. The way of stress on the upper body

2.2. Analysis of the static characteristics of the bed

Using the data interface between SolidWorks and Workbench, the SolidWorks dimensional parameters are directly imported into Workbench, and then the optimized dimensions can also be directly modified to SolidWorks through Workbench, such data interaction is of great importance in practical work applications. Therefore, the SolidWorks model of the bed body shown in Figure 5-5 is imported into Workbench, and Workbench software is used to analyze the static properties of the bed body and modal analysis, and obtain the corresponding analysis results, before the analysis of the model, set its relevant parameters, as shown in Table 1 and Table 2.

Table 1. Bed material parameters

Material	Density	Modulus of elasticity	Poisson's ratio
HT300	7300Kg/m^3	13000MPa	0.25

Table 2. Finite Element Meshing Parameters

Mesh Type	Grid Size	Number of cells	Number of Nodes
Solid187	10mm	1716490	2654049

2.3. Analysis of bed dynamic characteristics

The results of the static analysis are shown in Figure 2, which is a cloud plot of the displacement distribution of the static characteristic analysis of the bed after the loading is completed. The figure shows that the integrated maximum bit displacement is 0.00213 mm, which is located at the end face of the bed. The maximum stress is 12.17 MPa, which is located at the inner end of the tail end, and the overall mass is 1380 kg.

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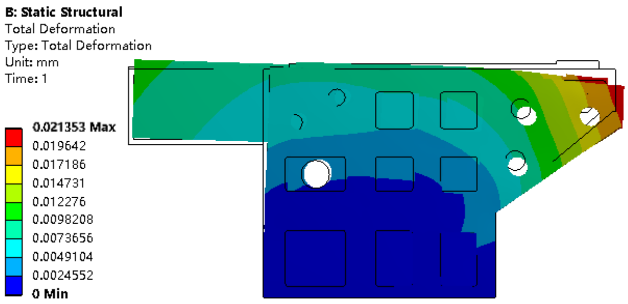

Figure 2. The way of stress on the upper body

The machine tool generates vibration frequencies due to the rotation of the spindle during actual machining, so the inherent frequency of the bed is reduced as much as possible while satisfying the condition of minimizing the deformation displacement.

The purpose of the modal analysis is to determine the vibration characteristics of the bed structure [4]. By analyzing the inherent frequency and vibration pattern of the target structure, it can be concluded whether the resulting inherent frequency is the same as the vibration frequency caused by the external system, and whether the structure is subject to resonance phenomena [5]. By using Block Lanczos method to extract the first 6 orders of modalities of the machine tool components, the modal analysis results are shown in Figure 3 1st order, 2nd order, 3rd order, 4th order, 5th order, 6th order amplitude displacement for the front end point of the bed, and its all 6th order intrinsic rate calculation results are shown in Table 3.

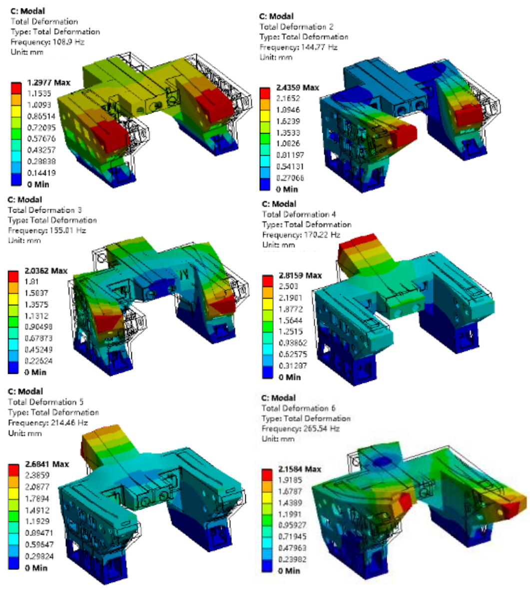

Figure 3. The way of stress on the upper body

According to the modal data in Table 3, the maximum inherent frequency of the machine tool components is 266.75 Hz. Since the speed of the machine tool increases slowly from low to high during the machining process, in order to reduce the bed resonance and ensure the accuracy and safety life of the machine tool, the optimization design will be aimed at reducing the 6th order inherent frequency.

Table 3. Bed material parameters

Number of steps	1	2	3	4	5	6
Frequency (Hz)	109.42	145.81	156.06	171.11	215.81	266.75

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3. Optimization of the upper bed body

The structural improvement of the bed of the machine needs to be determined with the load on the bed under extreme conditions, according to the analysis of Figure 4, the displacement of the bed under extreme conditions after the load appears at the front end, the preliminary analysis of the reason is due to the structure of the front for the projection structure, the structure lacks support caused by the poor stiffness. Therefore, the improvement of the bed body as shown in Figure 4, mainly in the front of the bed body added two pieces of reinforcement plate, the original quadrilateral profile into a triangular profile, in order to increase the rigidity of the bending deformation under extreme load.

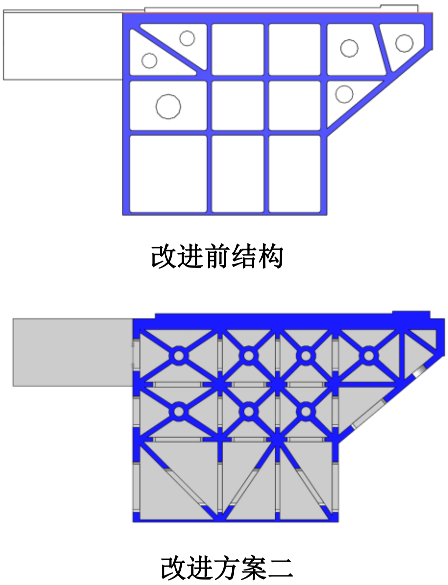

Figure 4. Modify the structure

Since the displacement of the bed under load is mainly concentrated in the front end, all the structural improvements are mainly aimed at strengthening the front end structure and the underside of the guide rail. As shown in Figure 5-19, two options for improvement are shown. Option 1 is mainly strengthened by adding diagonal reinforcement plates, and option 2 is mainly strengthened by adding cross cylinders, and the subsequent finite element analysis will be performed in ANSYS.

As shown in Fig. 5, the FEM analysis before and after the modification, the maximum deformation of scheme 1 is reduced from 21.3μm to 11.9μm under extreme load, in which the mass is 1542kg, compared with the pre-modification structure gravity increased by 162kg; the maximum deformation of scheme 2 is reduced from 21.3μm to 9.3μm, compared with the pre-modification structure gravity increased by 369kg. Through the analysis, the optimized parameters before and after the improvement are shown in Table 4.

As the displacement of Option 1 and Option 2 are reduced by 44.1% and 56.3%, respectively, but the mass is increased by 11.7% and 26.7%, respectively. Considering the manufacturing cost and processing difficulty, Option 1 was finally selected as the design reference. After improving the structure, by comparing the parameters, compared with before the improvement, it shows that the improved structure has good effect on the overall accuracy improvement.

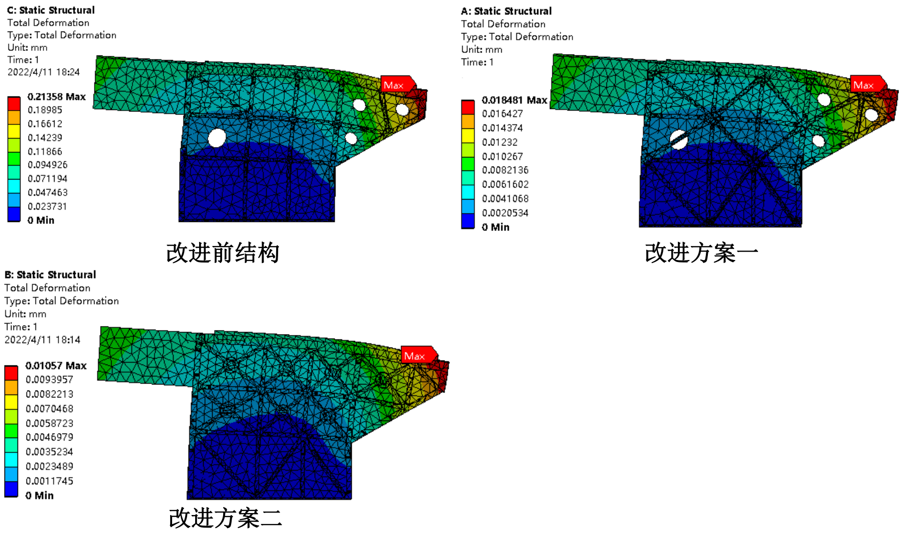

Figure 4. Finite element analysis before and after modification of the structure

Table 4. Bed material parameters

Parameter Comparison	Before	Program 1	Program 2
Maximum deformation	21.3μm	11.9μm	9.3μm

4. Conclusion

As the displacement of option 1 and option 2 are reduced by 44.1% and 56.3% respectively, but the quality is increased by 11.7% and 26.7% respectively. Considering the manufacturing cost and processing difficulty, Option 1 was finally selected as the design reference. After improving the structure, by comparing the parameters, compared with before the improvement, it shows that the improved structure has good effect on the overall accuracy improvement.

Acknowledgments

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