Modal Analysis of Spindle System of Vertical Machining Center Based on Workbench

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Abstract

In the process of using the vertical machining center to process the workpiece, the spindle system is affected by the cutting resistance, which result in the structural rigidity of spindle system changes, so that the natural frequency of the spindle system changes. Considering above problems, modal analysis of the machining process of the spindle system is carried out in this paper, and the natural frequency and vibration pattern of the spindle system can be obtained in this situation. In addition, the free mode of the spindle system under zero constraint is analyzed. By comparison, the influence of cutting resistance on the natural frequency and mode shapes e of the spindle system can be obtained during the machining of the workpiece.

Keywords

Spindle System, Modal Analysis, Natural Frequency, Vibration Pattern.

1. Introduction

Vertical machining centers in the machinery industry is widely used, the spindle system as the core components of machining parts is the focus of researchers. During the process of the vertical machining center processing a workpiece, the impact of the cutting tool when in the workpiece or cut out of the workpiece, or intermittent cutting surface processing occurs when the impact of intermittent cutting will cause the system to force vibration. In this case, the structural rigidity and natural frequency of the spindle system changes, which will affect the dynamic characteristics of the spindle system. The dynamic characteristics of the spindle system have a direct impact on the machining accuracy and cutting efficiency of the machine tool, affecting the surface roughness, cutting tool life and noise [1]. Therefore, it is necessary to perform modal analysis of the vertical machining center to understand its dynamic characteristics so as to be optimized and improved subsequently.

Many researchers have conducted research on how to perform modal analysis. For example, T.B.Yu [2] et used Pro / E to establish a three-dimensional model of the spindle system of a super-high-speed grinding machine, and then conducted modal analysis in ANSYS. J.Z.Yang [3] established a three-dimensional model of shale shaker using SolidWorks, and then conducted modal analysis based on Workbench. B.J. Qiu [4] established a parametric finite element analysis model of sprayer boom directly in ANSYS and carried out modal analysis. Due to the complex structure of spindle system in vertical machining center, this paper will use Creo software to establish the three-dimensional model and then perform modal analysis in the Workbench software. The specific content will be introduced in detail in folowing.

2. Theory of Modal Analysis

Modal analysis is a method of studying structural dynamic characteristics based on the vibration theory and modal parameters. The modal parameters include the natural vibration frequency and mode shape generally.The mechanical structure of the dynamic analysis of the finite element equation [5] is as follows:

$$[\mathbf{M}]\{x''\}+[\mathbf{C}]\{x'\}+[\mathbf{K}]\{x\}=\{f(t)\} \quad (1)$$

In the formula, [M] is the total mass matrix of the component, [C] is the total damping matrix of the component, [K] is the total stiffness matrix of the component, {x ''} is the acceleration vector, {x '} is the velocity vector, {x}refers to the displacement vector, {f (t)} is the force vector.

By solving the formula (1), the inherent characteristics of the structure vibration system such as the natural frequency and mode shape as well as the dynamic response such as displacement, velocity, acceleration, stress and strain can be obtained.

3. Three-Dimensional Solid Modeling of the Spindle System

Since the spindle system of vertical machining center is assembled from multiple parts, it is difficult to build a model directly in the Workbench software. Hence, this paper uses Creo software, a professional three-dimensional modeling software, to establish a three-dimensional solid assembly model of the spindle system, and save the assembly model as x_t format file for import into the Workbench software subsequently to perform modal analysis. The three-dimensional solid model of the spindle system is shown in Fig. 1.

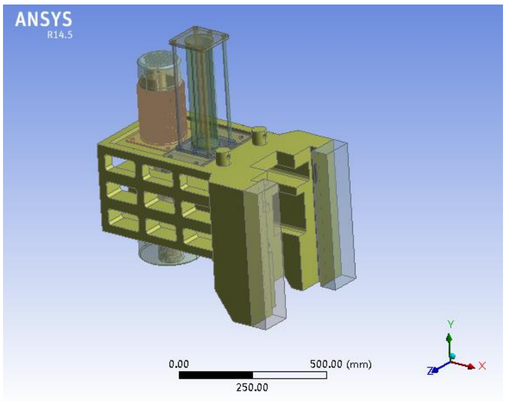

Fig. 1 The three-dimensional solid model of the spindle system

4. Modal Analysis of Spindle System

In this paper, the free-form modal analysis and prestress modal analysis of the spindle system are performed respectively. Prestress modal analysis takes the loading, constraints of the workpiece into account in the processing process by spindle system. Take the static analysis first, and then perform modal analysis rely on the static analysis results. Before the analysis, it is necessary to set the material properties and meshing for the imported 3D solid model. The grid model of spindle system is shown in Fig. 2.

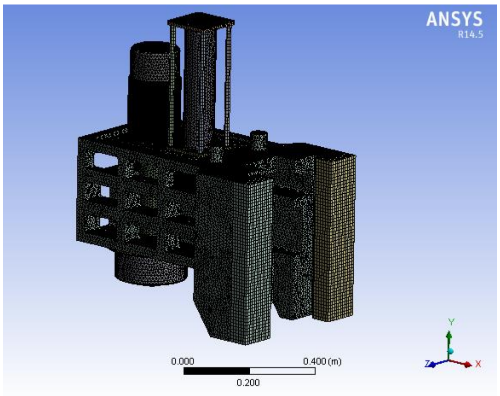

Fig. 2 The speed distribution of the runner with different expansion angle

The vibration of the spindle system is theoretically superposed by the infinitesimal mode, but the contribution of each mode for the vibration is different in the actual situation. In general, the first mode plays a leading role. Therefore, after the modal analysis of the spindle system is completed, the first-order modal analysis results are read only in this paper.

When perform free modal analysis, any restraint and load does not exert on the spindle system. Reading the analysi result, the nature frequency of the system can be obtained as 3.27E-3Hz. At this time, the first-order vibration pattern of the system is shown in Fig. 3.

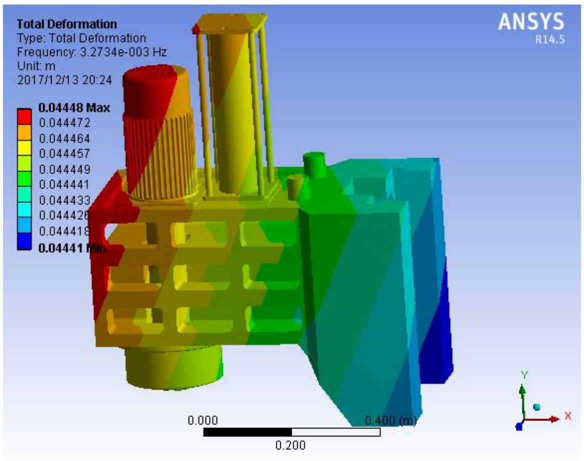

Fig. 3 The first-order vibration pattern for free mode

In the process of using the vertical machining center to process the workpiece, affected by the cutting resistance, the structural rigidity of the the spindle system changes, that resulting in its natural frequency changes. In order to improve the dynamic performance of the equipment, prestress analysis of the spindle system is very necessary.

When the workpiece is machined, the horizontal cutting resistance of the spindle system is 1KN and restrains the displacement of the right guide rail at the same time. After the static analysis, the equivalent stress cloud of the system can be obtained, as shown in Fig. 4. It can be seen that the spindle system meet the strength requirements entirely from the stress cloud map.

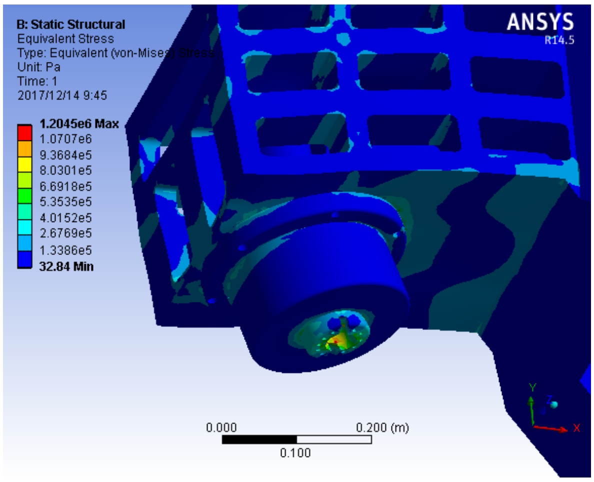

Fig. 4 Equivalent stress cloud of the system

Based on the statics analysis results, the prestressed modal analysis of the spindle system is performed. After the analysis, it can be seen that the first-order natural frequency is 208.02 Hz, and the corresponding first-order vibration pattern is shown in Fig. 5. As can be seen from the Fig. 5, the vibration occurs mainly in the cylinder, the other parts are relatively stable.

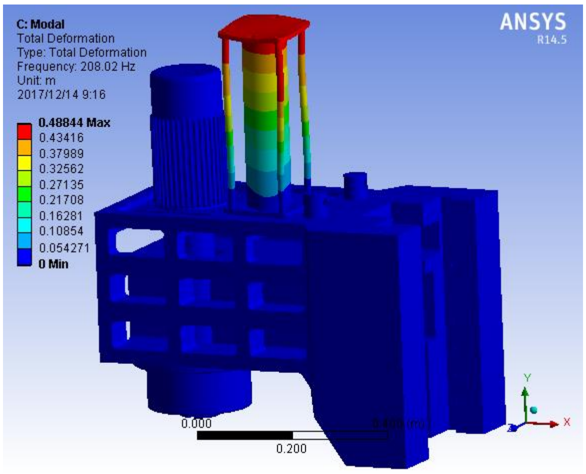

Fig. 5 The first-order vibration pattern for prestressed mode

6. Conclusion

In this paper, the spindle system of vertical machining center is taken as the research object, a three-dimensional solid model of spindle system is established in Creo software. The established three-dimensional model is imported into the Workbench software, and the free modal analysis and the prestress modal analysis are performed respectively to obtain the natural frequency and mode shapes in the two situations. It can be seen from the analysis results that the cutting resistance force will changes the natural frequency of the system during machining, and the influence on the cylinder is the greatest when the forced vibration occurs.

Acknowledgements

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References

[1] L.G. Cai, S.M. Ma, Y.S. Zhao, Z.F. Liu, W.T. Yang: Finite Element Modeling and Modal Analysis of Heavy-duty Mechanical Spindle under Multiple Constraints, JOURNAL OF MECHANICAL ENGINEERING, Vol.48(2012),No.3, p.165-173.

[2] T.B. Yu, X.Z. Wang, P. Guan, W.S. Wang: Modal Analysis of Spindle System on Ultra-high Speed Grinder, JOURNAL OF MECHANICAL ENGINEERING, Vol.48(2012), No.17, p.183-188.

[3] J.Z Yang: Modal Analysis for Aulti-angle Vibrating Screen Based on ANSYS Workbench, JOURNAL OF CHINA COAL SOCIETY, Vol.37(2012), No.1, p. 240-244.

[4] B.J. Qiu, Y.J. He, Y.H. Sheng, Z.H. Ying, W.Q. Deng: Finite Element Modal Analysis and Structure Optimization of Spray Boom, Transactions of the Chinese Society of Agricultural Machinery, Vol.458(2014), No.8, p. 112-116.

[5] F.Z. Li, S.G. Tong, X.B, Wang: Dynamic Optimization Design for Working Device of Hydraulic Excavator Based on Modal Analysis, Transactions of the Chinese Society of Agricultural Machinery, Vol.45(2014), No.4, p. 28-36.