The Finite element Analysis and Research of high-speed motorized spindle in static and dynamic performance

[1,a]Kepeng Zhang Changchun Shang[2,b] Yuyu Hao[3,c] Yuanying Du[4,d]

[1,2,3,4]Xi'an University of Science and Technology, Yanta District, Xi'an, Shaanxi Province, China

[a]netwodeshijie@126.com, [b]545834818@qq.com, [c]526112499@qq.com, [d]562295292@qq.com

Keywords: High Speed Motorized Spindle, Static and dynamic performance, Finite Element Analysis

Abstract. In High Speed Motorized Spindle for the study, To establish motorized spindle dimensional simplified model In Pro/E and imported in ANSYS Workbench, By setting the related parameters, select the type of grid and division, load and boundary conditions' computing, Through static analysis and modal analysis of motorized spindle unit in ANSYS Workbench, Geted motorized spindle static stiffness, natural frequencies and vibration mode, The results show that motorized spindle static stiffness able to meet the design requirements; The maximum operating speed motorized spindle is far below the critical speed of the first order, Can effectively avoid the occurrence of resonances. Through the static and dynamic characteristics analysis motorized spindle, Validate the reasonableness of motorized spindle design, But also for the subsequent structural optimization foundation for motorized spindle

Introduction

High speed motorized spindle as a core component of high-speed machine , Its structure performance largely determines the overall level of high-speed machining , at present the development of motorized spindle has matured, its structure and shape has been basically stable. Usually the study for motorized spindle included static and dynamic performance and Hot Performance, the static and dynamic performance of motorized spindle consists mainly inherent dynamic performance and dynamic response performance, Hot Properties of motorized spindle were temperature rise and deformation under internal heat effect. A complete motor spindle unit system mainly consists of motor, bearings, motor cooling system, bearing automatic unloading system, bearing lubrication and cooling systems, pulse coding system and so on.

High Speed Motorized spindle simplified model and finite element modeling

Static performance of High Speed Motorized Spindle means the ability to resist deformation under static external loads. The main motorized spindle by the rotating pieces (shaft, rotor, sleeve, etc.), a support pieces (bearing) and the fixed pieces (housing, stator, etc.) components. Fittings for motorized spindle affect the mechanical properties of the analysis will not be ignored. The motorized spindle finite element models simplified are as follows:

a) The bearing simplified to elastic support, and with an elastic constraint simulates;

b) Motorized spindle rotating parts will be processed by a whole, and has the same properties;

c) Only consider the radial stiffness of the bearing, and assumed to be constant.

According to the above simplified method, the simplified geometric model of the finally obtained as shown in Fig.1.

Using Simulation in ANSYS Workbench module to create a finite element model motorized spindle unit. First select Geometry> From File, selected Design Modeler and created the motorized spindle three-dimensional solid model files in it, as shown in Figure 2; Second for the spindle adding material 40CrNi, modulus of elasticity $E=2.1\times10^5 N/mm^2$, poison's ratio $\mu=0.28$, as shown in Figure 3;

Finally, in the mesh's sub-menu—method and sizing, set the grid type and mesh size (value 5mm), ultimately obtained finite element model of electric spindle unit after to meshing shown in Figure 4.

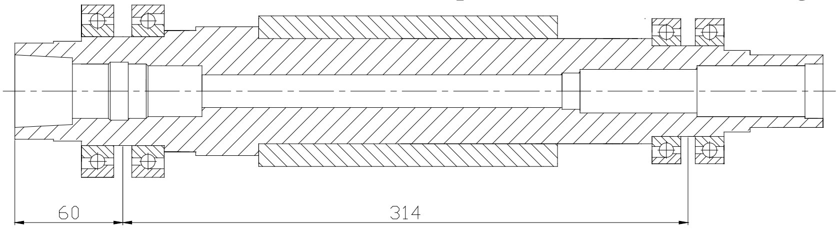


Fig.1 The simplified model of electric spindle static and dynamic analysis

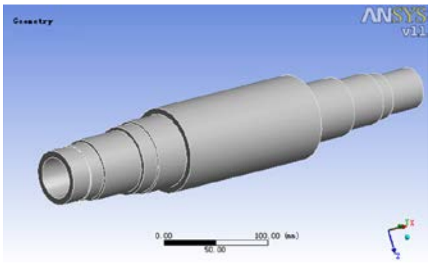


Fig.2 Importing geometric model

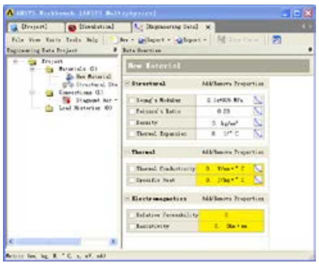


Fig.3 Adding Material Information

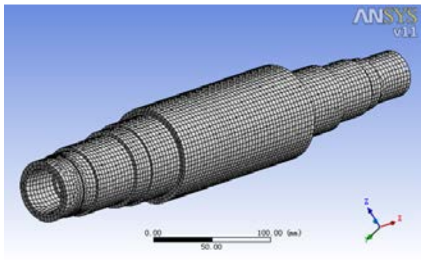


Fig.4 Finite element model

The calculate, loading, constraint and solve to static load of high speed motorized spindle

Motorized spindle static external loads main considerations for cutting force($F_{cav\Sigma}$) when cutting, the spindle speed of high-speed machining is greater than 10000r/min, climb cutting for high speed steel end mills, cutter diameter(d_0) were 32mm, number of teeth(Z) were 4, the amount of feed per tooth(f_Z) were 0.08mm/Z, every routing depth(a_p) were 20mm, side of cut(a_e) were 2mm, the workpiece material was 45 steel, so:

$$F_{cav\Sigma} = 9.81 C_{Fc} a_p Z_e d_0^{b_c} a_e^{e_c} f_z^{u_c} \quad (1)$$

In the formula: C_{Fc} was coefficient, and b_c, e_c, u_c were exponent, Obtained by referring to the mechanical design manual:

$$C_{Fc}=68.2;\quad b_c=-0.86;\quad e_c=0.86;\quad u_c=0.72 \quad (2)$$

So the cutting force($F_{cav\Sigma}$) was 787.1N. When the high-speed milling machining, the radial load(F_r) can be decomposed into longitudinal direction force and component(F_l) and horizontal component (Ft), The ratio of each component of the experience for milling:

$$F1/Fc=0.8\text{~}0.9;\quad Ft/Fc=0.35\text{~}0.4 \quad (3)$$

So can be obtained:

$$F_l=669\text{N};\quad F_t=279\text{N};\quad F_r=\sqrt{F_l^2+F_t^2}=725\text{N} \quad (4)$$

When the electric spindle system static analysis, mainly cutting force load analysis, radial load (F_r =725N) applied on the front spindle node, set the boundary conditions for motorized spindle should be considered the elasticity of the bearings, front and rear pairs of angular contact ball bearings radial stiffness are:

$$K_1=314\ \text{N}/\mu\text{m},\quad K_2=270\ \text{N}/\mu\text{m} \quad (5)$$

In the ANSYS workbench module static structural, for finite element model loads, constraints and solving, figure 5 is an added load and constraints for motorized spindle model. Because static analysis of High Speed Motorized Spindle is to study its static deformation, under typical force conditions the radial force to be concentrate power form, Simulate tool tip position were applied in front spindle, eventually can be solved and got high-speed spindle static deformation, as shown in Figure 6.

As can be seen from Figure 6 after electric spindle by cutting force, Where the greatest amount of deformation appear in front spindle and the δ was 1.8μm, so we can be obtained Motorized spindle static stiffness by formulas, that static stiffness (K) was 403N/μm, greater than for Motorized spindle static stiffness requirements (225N/μm), So spindle static stiffness to meet the requirements.

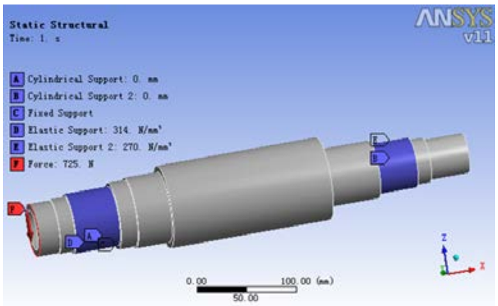


Fig. 5 Add loads and constraints for Motorized spindle model

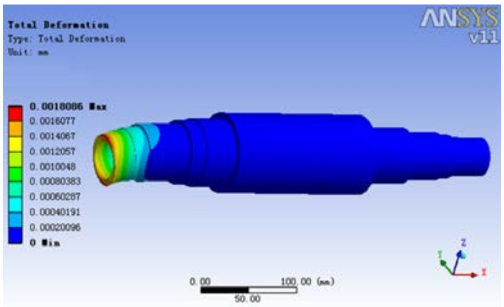
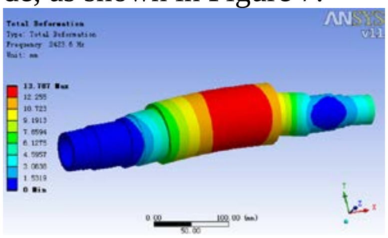


Fig. 6 High Speed Motorized Spindle static deformation maps

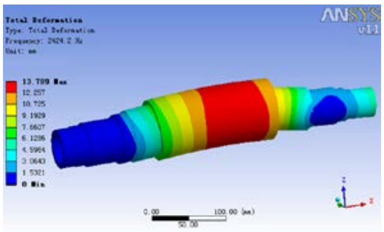
The dynamic performance analysis of high speed motorize spindle base on ANSYS Workbench

Dynamic performance of mechanical systems mainly related the natural frequency and external stimuli of systematic; it is mainly for analysis of high-speed Motorized spindle modal characteristics that the time kinetic study of high-speed spindle. Modal analysis is the basis of dynamic performance analysis, its main task is to determine the mechanical structure of the system's natural frequencies and mode shapes. The use of ANSYS Workbench for High Speed Motorized Spindle modal analysis, at this point the material information required to set, definition of the modulus of elasticity (E) was 2.1*105N/mm, Poisson's ratio (μ)was 0.28 and Density(ρ) was 7900kg/m^3, The following is an analysis of its finite element model in the software.

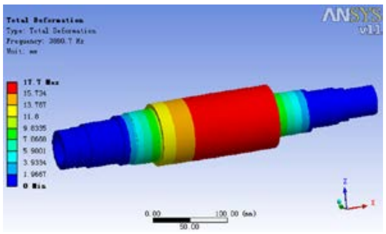
Applied to the constraint for First, modal analysis of dynamic performance analysis only related object structure size parameters, material parameters, and regardless of the amount of force applied, the rotational speed, same way as static analysis methods of applied to constraints; Second set solving (result) parameters, taking into account the lower modes is larger than the higher modes of vibration of mechanical structures, Therefore, when analysis the system modal of the mechanical structure, typically extracted 5 to 10 its modal can be, the modal analysis of the electric spindle set to solve the first six modal; Finally, it obtained the solving results in the Tabular Date, Select Solution> Total Deformation, specify first modal main modes and press solving, you can see the dynamic model of the first order main modes of motorized spindle, Similarly it can be obtained several other vibration mode, as shown in Figure 7.



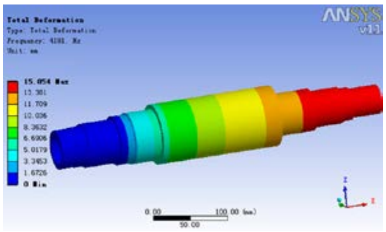
a) First-order mode chart



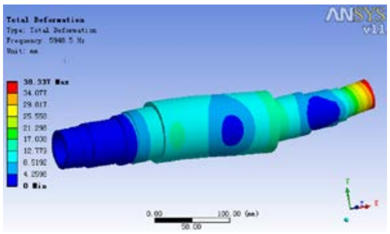
b) Second -order mode chart



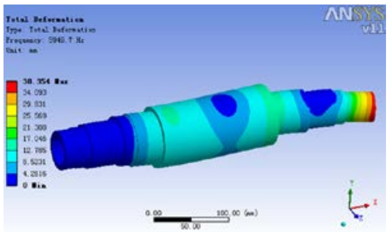
c) Third -order mode chart



d) Fourth-order mode chart



e) Fifth-order mode chart



f) Sixth-order mode chart

Fig.7 Various vibration mode chart of electric spindle in ANSYS Workbench

Through the above vibration mode chart of motorized spindle observations, You can get their first six natural frequencies and vibration mode, as shown in Table 1.

Table.1 Motorized spindle before six natural frequencies and mode shapes

Order	First	Second	Third	Fourth	Fifth	Sixth
Frequency	2425.7	2430.9	3875.5	4183.4	5951.2	5954.7
Vibration mode	First-order bending	Second-order bending	Radial expansion	Axial tensile	First-order swinging	Second-order swinging

From the above results of the modal analysis: The first two natural frequencies of the value of the electric spindle were less, and the vibration mode were orthogonal, so think they are repeated roots; By the same token, the fifth-order and the sixth-order of the motorized spindle natural frequency values are also repeated roots.

Summary

This paper introduced the high-speed Motorized spindle static and dynamic characteristics of the concept, using finite element analysis software ANSYS Workbench, it analysis the static and dynamic performance of modal analysis for simplified motorized spindle of three-dimensional finite element model. By analyzing both the results showed that: the static stiffness of motorized spindle can meet the design requirements; the maximum operating speed of motorized spindle was far below the critical speed of the first order, it can effectively prevent the occurrence of resonances. Through the motorized spindle static and dynamic characteristics analysis, validate the reasonableness of motorized spindle design, but also for the subsequent structural optimization of motorized spindle laid the foundation.

References

[1] Kaiyu Chu. CNC high-speed spindle technology and its development trend[J]. Machine Tool & Hydraulics, 2006(10):228-230.

[2] Yanlin Chen, Zhishan Duan, Wanli Xiong. Current research and development of high-speed spindle technology[J]. Mechanical Research & Application, 2004,17(4):10-11.

[3] Bing Li, Zhengjia He, Xuefeng Chen. ANSYS Workbench design, simulation and optimization[M]. Beijing: Tsinghua University Press,2008.

[4] Shaolong Wu, Yuanxiang Zhang. Based on high-speed spindle dynamics analysis ANSYS Workbench[J]. Modular Machine Tool & Automatic Manufacturing Technique,2010(9):20-26.

[5] Zhao Bai, Ping Ma, Ailing Hu. Application of the finite element method to optimize the design of high-speed spindle[J]. Machine Tool & Hydraulics, 2004(10):126-128.

[6] Dapeng Rui, Yuhou Wu, Ke Zhang. Ceramic spindle speed analysis and calculation of heat[J]. Mechanical Engineer,2005(12):110-111.

[7] Zuowei Yang, Guofu Yin, Xin Shang. High-speed electric spindle thermal characteristics and dynamics coupling analysis model[J]. Jilin University (Engineering Science),2011,41(1):100-105.

[8] Jun He, Yuhuo Lai, Xirong Luo. Spindle system thermal-based ANSYS Workbench - Structural Coupling Analysis[J]. Modular Machine Tool & Automatic Manufacturing Technique,2011(7):19-22.