CHEMICAL ENGINEERING TRANSACTIONS
VOL. 59, 2017
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet
Guest Editors: Zhuo Yang, Junjie Ba, Jing Pan

ISBN 978-88-95608- 49-5; **ISSN** 2283-9216
DOI: 10.3303/CET1759012

Research on the Optimization Design of Spindle Load of CNC Machine Tools

Xionghui Long*, Dan Su

Guangzhou Institute of Railway Technology, Guangzhou 510000, China
XionghuiLong@126.com

This paper established the finite element machine tool spindle and accessories model, accurate simulation of the boundary conditions, constraints and external loads, and the analysis of static and dynamic characteristics of spindle, the spindle optimization design based on ANSYS software, the performance comparison before and after optimization of the spindle; according to the results of optimization design and design experience of spindle. Analysis and interval of each size most likely made spindle, combined with orthogonal design method, the change of the size of the spindle under the condition of static and dynamic performance analysis of the spindle, and then obtain the optimal combination of the size of the spindle, spindle performance comparison optimal size composition and original spindle; based on the analysis results of different combinations of spindle size the static and dynamic performance of the orthogonal experiment, the response surface method were obtained and the performance function related to deflection and strength and modal The performance function, and considering the influence of spindle performance uncertainties, the reliability optimization design of spindle, spindle performance analysis of the optimized and the original spindle; integrated optimization design results of the comparison of the three methods shows: considering the uncertainty of the optimization design can according to the actual situation on the basis of improving the performance of the spindle.

1. Introduction

In recent years, our country and the developed countries in the world increasingly close ties between the increasingly fierce competitions, the equipment manufacturing industry has become related to China's international status and industrial revitalization and national prosperity of the important symbol (Liu et al., 2016). Compared with foreign CNC machine tools, CNC machine tools in our country are reasonable in price, relatively mature in technical specifications, and have certain market competitiveness (Zhu et al., 2015). Universal milling head diagram as shown in Figure 1, Longmen CNC boring machine universal milling head is one of the core components, divided into spindle type and mechanical spindle two categories. Electric spindle is mainly used in high speed finishing, such as high speed rail train industry, such as aluminum alloy, titanium alloy, high temperature resistant alloy and composite material, such as high-strength lightweight parts. Mechanical spindle type is mainly used in high torque strong cutting, such as the energy industry of the turbine blade, the ship industry, such as screw propeller parts (Zhou and He, 2015). Longmen boring machine spindle type universal milling head has two mutually perpendicular planes of rotation, not only can complete the milling work in machining surface, can be obtained through various spindle position universal milling head horizontal and oblique axes of rotation, in order to adapt to the different requirements of the edges, grooves and other processing various parts in particular, it has important practical value in the two maintenances. Longmen GMC2000 boring machine universal milling head with double swing head is the appropriate speed, dynamic angle, An axis swing angle of plus or minus 110 degrees, C axis swing angle + 360 degrees. The tool center is always maintained in the normal direction of the work piece, and avoids zero cutting speed. Electric spindle rotary tool, high speed (up to 24000rpm), especially suitable for processing mound and non-ferrous metal materials, can also be different spindle power and torque configured according to user requirements, CNC machine tool structure schematic diagram shown in Figure 1.

Please cite this article as: Xionghui Long, Dan Su, 2017, Research on the optimization design of spindle load of cnc machine tools, Chemical Engineering Transactions, 59, 67-72 DOI:10.3303/CET1759012

Figure 1: Schematic diagram of universal milling head and Schematic diagram of the structure of NC chine tools

The spindle is the core component of the universal milling head, whose function is to drive the cutting tool (grinding wheel) to rotate. The spindle has a great influence on the machining accuracy, surface quality and productivity. With the development of modern industry to the requirement of machine machining precision and efficiency increasing requirements on the performance of machine tools spindle is higher: wide speed range, high precision, high rigidity, small vibration, low noise, small deformation, and has good resistance ability of forced vibration and self-excited vibration. (Wan, 2014).

2. Literature review and theoretical exposition

2.1 Introduction to finite element method

Finite element method (FEM) is a kind of highly effective and commonly used numerical method. The field of scientific computing, often need to solve all kinds of differential equations, and many analytical solutions of differential equations is generally difficult to obtain, using the finite element method of differential equation is discretized, can be programmed using computer aided solution. The solution domain discrete continuous combined body of a unit, the approximate function hypothesis in each unit to slice representation of the unknown field function solution domain to solve, approximate function is usually expressed by the unknown function and its derivative numerical interpolation function at each node unit (Zhang et al., 2014). Thus, a continuous infinite degree of freedom problem is transformed into a discrete finite degree of freedom problem. Feng Kang summed up this, made systematic theoretical results (Liu et al., 2015). The finite element method solving domain is discretized into finite element (grid), unit node connection between nodes, transfer interaction between units, node field as a function of the unknown quantity, and piecewise difference field distribution simulation function, and solving. Therefore, the complicated engineering problem is reduced to a simple problem with high accuracy, and the stress and strain distribution of the element is shown in Figure 2.

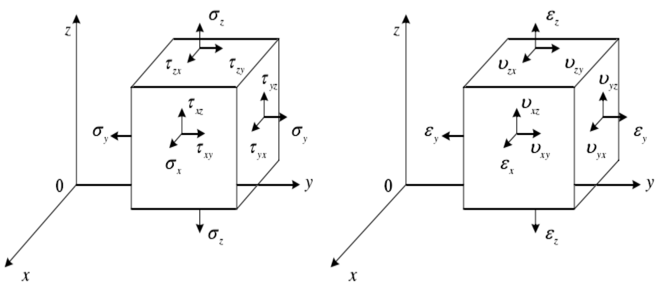

Figure 2: Schematic diagram of element stress and strain distribution

2.2 Basic theory of orthogonal test design

In order to determine the optimal combination of factors, the authors put forward a kind of fast and efficient experimental design method, orthogonal test design (Duan and Ding, 2015). The orthogonal test design is a design method of optimal level for multi factor experiment, which is based on the orthogonality of the selected part of the comprehensive test representative, the test of representative and comprehensive test compared with the equilibrium dispersion characteristics of neat comparable". The orthogonal test design is a scientific method for the design and analysis of a proper orthogonal table. The orthogonal design is a design method of multi factors and multi levels, it is based on the orthogonality selected from comprehensive test of some representative points test, and these representative points have "evenly dispersed, neat features than the orthogonal test design is the main method of fractional factorial design. Suppose that a comprehensive test of the three factors, each of which has three level tests, then we need 33 =27 test, comprehensive experiments of three factors and three levels of the diagram as shown in Figure 3, in the orthogonal test, each level of each factor and each factor collocation are uniform, only three times the test. So the orthogonal test can get almost the same effect as the full-scale experiment. In the three combinations, the level of factor B and factor C is only one of the three levels of factor A, which is the same as the. That is to say, if we compare three influence factors of A level of the test results, the experimental groups containing A1, A2, A3 were added, B and C for the factors of A, equivalent to a fixed.

		C_1	C_2	C_3
A_1	B_1	$A_1B_1C_1$	$A_1B_1C_2$	$A_1B_1C_3$
	B_2	$A_1B_2C_1$	$A_1B_2C_2$	$A_1B_2C_3$
	B_3	$A_1B_3C_1$	$A_1B_3C_2$	$A_1B_3C_3$
A_2	B_1	$A_2B_1C_1$	$A_2B_1C_2$	$A_2B_1C_3$
	B_2	$A_2B_2C_1$	$A_2B_2C_2$	$A_2B_2C_3$
	B_3	$A_2B_3C_1$	$A_2B_3C_2$	$A_2B_3C_3$
A_3	B_1	$A_3B_1C_1$	$A_3B_1C_2$	$A_3B_1C_3$
	B_2	$A_3B_2C_1$	$A_3B_2C_2$	$A_3B_2C_3$
	B_3	$A_3B_3C_1$	$A_3B_3C_2$	$A_3B_3C_3$

Figure 3: Schematic diagram of comprehensive experiments of three factors and three levels

2.3 Orthogonal experiment design

The orthogonal test design includes: designing orthogonal test scheme, orthogonal test, calculation and analysis of the experimental results and the four parts of the test. The first step is to clarify the purpose of the design. In the orthogonal design, the first step is to clarify what is the purpose of the test, or what is the reason, which is the basis of orthogonal test. After determining the purpose of the experiment, then determine the corresponding test indicators. The test index is a measure of the value of the experimental results. Secondly, choose the appropriate factors and factors (Wang et al., 2016). The first step and the second step are very dependent on the experimental design experience and expertise of the experimenter. A good experimenter can successfully complete the orthogonal test, and get good results. Secondly, choose the orthogonal table and table design. The reliability optimization design considering random variables and interval variables can obtain the optimal combination of design variables under the condition of ensuring the reliability of the results. In this section, we mainly introduce the reliability optimization design of double loop, which is the reliability optimization design under the condition of random variables and interval variables (Yang, 2016). The results of the orthogonal test results are shown in Figure 4, and the core codes are listed as follows (Li and Zhang, 2016).

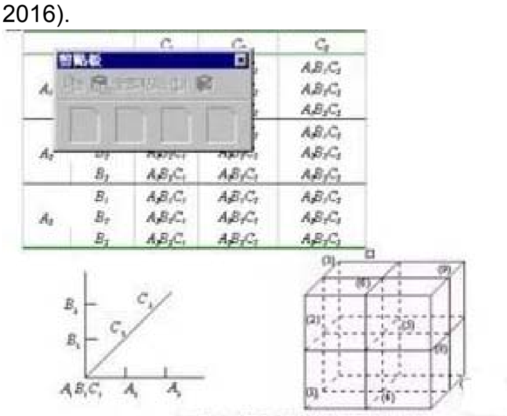

Figure 4: Schematic diagram of digital building technology

1. settings = cordexch(3,13,'q'); % settings; 2. mr = p(2,:); % mr: middle row, i.e., middle level 3. mr = mr(ones(13,1),:); 4. hr = (p(1,:) - p(3,:))/2; 5. hr = hr(ones(13,1),:); 6. expCond = settings.*hr + mr; 7. p1 = expCond(:,1); 8. p2 = expCond(:,2); 9. p3 = expCond(:,3); 10. y = zeros(13,1); 11. for k = 1:13; 12. y(k) =

1.25*(p2(k) - p3(k)/1.5183)./(1 + 0.064*p1(k) ... ; 13. + 0.0378*p2(k) + 0.1326*p3(k))*normrnd(1,0.02); 14. end; 15. data = [expCond y]; 16. settings = cordexch(3,13,'q'); % settings; 17. mr = p(2,:); % mr: middle row, i.e., middle level; 18. mr = mr(ones(13,1),:); 19. hr = (p(1,:) - p(3,:))/2; 20. hr = hr(ones(13,1),:); 21. expCond = settings.*hr + mr; 22. p1 = expCond(:,1); 23. p2 = expCond(:,2); 24. p3 = expCond(:,3); 25. y = zeros(13,1); 26. for k = 1:13; 27. y(k) = 1.25*(p2(k) - p3(k)/1.5183)./(1 + 0.064*p1(k) ...; 28. + 0.0378*p2(k) + 0.1326*p3(k))*normrnd(1,0.02); 29. end; 30. data = [expCond y]

3. Finite element analysis and optimization design of spindle

3.1 Analysis and calculation of spindle and bearing

The main content of this chapter is the quantitative analysis of the external forces of the spindle components, simplifying the combination of bearing parts and bearings and spindle, the establishment of accurate digital simulation model, in order to analyze the static and dynamic characteristics of the spindle. Finally, the optimal design based on ANSYS software. In order to establish the finite element model of the spindle is simple and effective, we must thoroughly understand the Longmen boring machine universal milling head structure and its operation mode. The cutting force decomposition is shown in Figure 5, the static and dynamic problems of the shaft, according to the combination between the bearing and the shaft and the bearing surface modeling problem, and the nonlinear contact problem of the bearing itself is not the focus, simplify the combination between the bearing and the shaft and the bearing surface does not affect the purpose of the study, but also improve the modeling speed and precision, and improve computing efficiency. Therefore, the bearing is simplified as a simple radial spring and damper characteristics by using the finite difference analysis model of Longmen boring machine spindle. The main intention of deformation icon as shown in Figure 5, in combination with the actual simulation of bearing and the bearing and the shaft surface, the node consolidation of the end of the spring on the main shaft, and the other end (P1, P2, P3, P4 four nodes) for complete consolidation, each radial stiffness (K/2 single row radial thrust ball bearing stiffness). The 3 column ball bearing front spindle with radial 3 columns of the same radial spring distribution to simulate the bearing stiffness, axial column using 3 axial spring simulation bearing stiffness; simulation above 2 column ball bearing spindle end. In the analysis and design of the spindle system, the bearing stiffness is one of the important factors, but due to the nonlinear bearing stiffness and bearing type, material, shape and other factors, so to accurately determine the bearing stiffness is not realistic. Zhu et al., the use of inductance measurement of a set of bearing stiffness test device, more accurate measurement of the stiffness of the bearing (Ma et al., 2014).

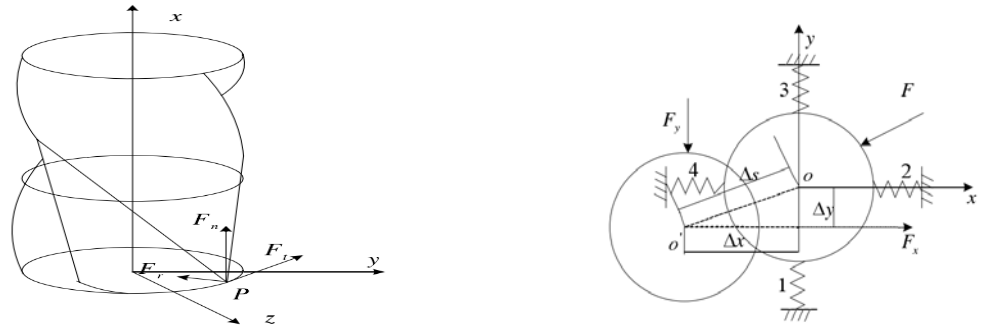

Figure 5: Schematic diagram of cutting force decomposition and Schematic diagram of spindle deformation

3.2 Spindle finite element analysis

Finite element analysis is the foundation of the whole research. It includes the selection of unit type, the establishment of numerical analysis model and finite element analysis. Determine the type of units required for the network before the model is established. The selection of unit type is based on the analysis of the complexity of the object, the characteristics of the stress and strain, the accuracy of the calculation requirements and the computing power of the computer. According to the characteristics of the solid modeling of the machine tool spindle system and the structural mechanical characteristics reflected in the motion, the SOLID45 unit is used to divide the machine tool spindle components. The SOLID45 element is used for 3D solid structure model for 3-D solid structure unit. The unit consists of eight nodes. Each node has three degrees of freedom in X, y, and Z, as shown in Figure 6 represents a deformed SOLID45 unit. SOLID45 unit can be simple control, more accurate simulation of the actual situation. The SOLID45 element can be used to simulate plasticity, creep and expansion, but also to meet the stress hardening, large deformation and large strain characteristics. In order to simplify the meshing of the bearing with COMBIN14 element, the element has the axial or torsional elastic damping properties of one-dimensional, two-dimensional or three-dimensional. The model is the basis of network, has a direct impact on the process of network model is reasonable. If the model is large and regular, ANSYS software provides a method for static analysis and dynamic analysis. In addition, the distributed computing method, the bandwidth optimization and the wave front processing method. Longmen GMC2000 boring machine spindle finite element model as shown in Figure 6, the internal model as shown in figure 6. In the model of the Z coordinates of the 126.5 small ladders, the analysis can be ignored. In order to more accurately simulate the axis in the work force, the axial force of the work directly loaded in the handle, so the handle part modeling as a part of the spindle. When the boundary condition is loaded, the rear end of the spindle does not change when the motion is carried out, so the rear end of the model spindle is completely fixed. Because the front-end milling cutter, so draw a solid. Finite element analysis is based on the solid grid. If the calculation precision of the result is high, the precision of meshing should be improved. Otherwise, the result of finite element analysis does not accord with the actual requirement, which will seriously affect the effect of the whole research project. If the structure of the research object is complex, the structure of the key part of the refinement of the grid, for example, the temperature gradient, stress gradient, large deformation of the structure, in the non-critical part of the coarse mesh. The purpose of model checking is to check whether the mesh is reasonable. However, because the model is not the geometry of the ideal rules, the actual grid cannot be a rule. So it is necessary to check the model in order to limit the deformation of the mesh to a certain extent.

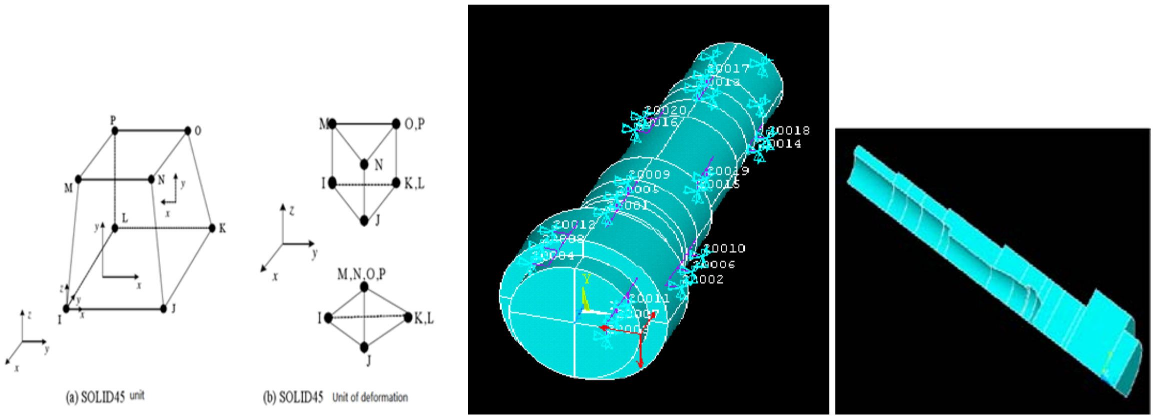

Figure 6: Schematic diagram of SOLID45 unit structure and Schematic diagram of the spindle structure after loading of spindle 1/4 boundary conditions and Schematic diagram

4. Orthogonal test design and analysis of spindle load

In this paper, we choose the comprehensive balance method to analyze the results of orthogonal test. The effects of different factors on the test results were different. The larger the range, indicating that the change of the factors in the test range will lead to the change of the test index, so the line is the biggest influence on the test results, which is the most important factor. To determine the optimal scheme, such as the index of the bigger the better, intuitive sake, draw the factors and indicators of the trend, the trend diagram as shown in figure 7, select the optimal scheme of comprehensive balance: 1 factors, 5 indexes are 3 level, the choice of 3 levels.

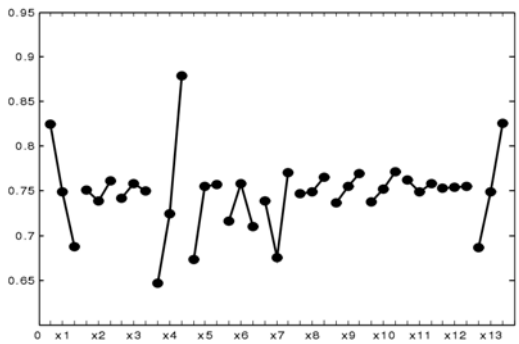

Figure 7: Schematic diagram of the trend factor

With the development of modern computer technology, and in-depth study of response surface method and improvement of the theory, the scientific computing model is becoming more and more complicated, the response surface method is obtained including chemistry, and biology and engineering favor (Hui et al., 2014). It has been proved that the response surface method has a high status in the field of engineering, such as reliability analysis, optimization design, dynamics research and engineering process control. In order to apply the two-order response surface approximation model, the first step is to find the optimal region by using the low order method, and then the polynomial approximation is used in the optimal region.

5. Conclusions

The importance of machine tool spindle is self-evident, many scholars devoted their lives to improve the performance of the machine tool spindle, and pay it to practice. Based on the optimization design of the spindle of the spindle, reduce weight, reduce material consumption and production cost, improve the working performance of the machine, can greatly shorten the design cycle of the spindle, and obtained the most consistent with the actual situation of the optimization method. An accurate finite element of machine tool spindle parts and accessories of the model, analysis of spindle of the static and dynamic performance, optimized design based on ANSYS software, and compared the performance of the spindle before and after optimization; response surface method were obtained and the performance function related to deflection, strength and modal based on the performance of the resulting function, comprehensive considering the influence of spindle performance uncertainties, the reliability optimization design of spindle and spindle after optimization and performance analysis of the spindle, and comprehensive optimization design results of the comparison of the three methods, the most practical method can greatly improve the spindle safety performance and processing performance.

Acknowledgments

This work is supported by the research and practice of Guangdong Province vocational education numerical control skill competition information platform construction (Guangdong education and scientific research "11th Five-Year" planning 2011 Annual project) (2011TJK252).

Reference

An Huping., Zhang Z., Yang T., 2014, Study on the design method of machine tool spindle parameters based on elastic deformation, Mechanical manufacture and automation, 5, 9-12.

Duan P., Ding X., 2015, The lightweight design of machine moving parts based on the theory of equivalent static load, Journal of University of Shanghai for Science and Technology, 37(6), 583-588.

Hui Y., Huang Y., Yang X., 2014, Since a full load turning center stiffness of bolted joint detection and design application, Journal of mechanical engineering, 50(17), 142-148.

Li R., Zhang L., 2016, The study on the estimation method of NC machine tool load stability collision probability design, Bulletin of science and technology, 32, 11,

Liu K., Luo W., Lai Y., 2015, Study on Optimization Design of machine tool spindle subspace method based on improved parallel, Electrical and mechanical engineering, 32(6), 788-792.

Liu S., Zhang Y., Wang H., 2016, Research on expert system of optimization of NC machine tool spindle, Journal of agricultural machinery, 47(4), 372-381.

Ma Y., Yue C., Hao S., 2014, Finite element analysis of the spindle of special machine tools of dark straight European wooden tenon, Journal of Northwest Forestry University. 29(1), 185-187.

Wan H., 2014, Vibration Analysis for the Spindle of Machine Tools under Cutting Loads, Modular machine tool and automatic manufacturing technique, 4, 22-25.

Wang C., Wang Y., Zou S., Peng L., Hu J., Yao Q., 2016, Modal analysis of high precision servo cnc camshaft grinding machine's grinding carriage, Machine Tool & Hydraulics, 3, 79-83.

Yang P., 2016, Radiation-based virus attack and defense reliability optimization design, Chemical Engineering Transactions, 51, 793-798, DOI: 10.3303/CET1651133.

Zhang S., Ma W., Li J., 2014, Study on the contact characteristics of high speed CNC machine tool spindle angular contact ball bearing, The bearing, 9, 1-5.

Zhou S., He X., 2015, Inch Hwayoung, spindle optimization design based on reliability analysis, Machine tool & hydraulics, 43(5), 164-166.

Zhu C., Nobu H., Li T., 2015, Optimization design of CNC machine tool spindle based on improved PSO algorithm, Chinese mechanical engineering, 26(20), 2784-2788.