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Reliability Analysis of CNC Machine Tool Spindle Under Random Cutting Load

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Abstract: According to the characteristic that deformation of high-speed moving CNC machine tool spindle under cutting load directly affects the accuracy stability and reliability, the finite element analysis model of machine tool spindle is established by using ANSYS. The relations of cutting load and spindle's largest tangential, axial and radial deformation are obtained. Considering the randomness of the cutting load when different parts are processed, takes the cutting load as a random variable and the spindle's maximum deformation as an output variable, the reliability calculation of the spindle is carried out by using the probabilistic finite element method, and the spindle's reliability under specified allowable deformation is obtained. A feasible analysis method is provided for reliability design of spindle and similar parts.

Keywords: spindle; cutting load; reliability; probabilistic finite element method

0 Introduction

As an important part of CNC machine, the spindle's reliability has a very serious influence on the CNC machine's reliability. And the deformation of spindle under cutting load will directly influence the machining quality and precision. So, a high reliability spindle under cutting load is very important to improve the machining quality [1].

There are lots of literatures studying on the spindle's cutting load and reliability. Haibo Wan [2] studied the vibration response of spindle under cutting load by harmonic analysis, but did not calculate the reliability of spindle. Caiyou Qin [3-5] etc although took the tip diameter, elasticity modulus and the deflection as random variables respectively to study the reliability of spindle, but they regarded cutting load as quota, without considering the effect of random load. In order to study the reliability of CNC machine tool spindle under cutting load, this article takes a lathe spindle as the object, builds the finite element analysis model by using ANSYS, analyzes the deformation of spindle under cutting load, and studies the reliability of spindle under random cutting load by using probabilistic finite element method.

1. Deformation of the spindle under cutting load

1.1 Dynamic simulation model of the spindle

A lathe spindle is drawn by using three-dimensional drawing software Pro/E. Local features such as keyway, chamfering, etc which won't affect the accuracy of calculation are ignored in order to improve the efficiency. The model is simplified as shown in Figure 1.

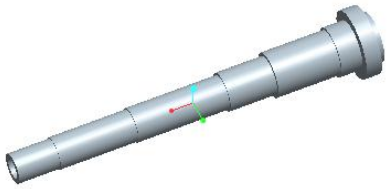

Fig. 1. Structure model of the lathe spindle

The model is imported into ANSYS, and the material properties is defined. The material of spindle is 45 steel, the elastic modulus is 210GPa, the Poisson's ratio is 0.31, the density is $7.85\times10^{3}Kg/m^{3}$. Then the 8 node element SOLID185 is used to mesh the model, gets the finite element model as shown in Figure 2.

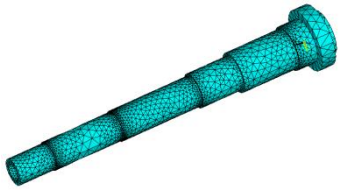

Fig. 2. Finite element model of lathe spindle

1.2 Harmonic response analysis

Harmonic response analysis can be used

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to get the displacement of spindle under excitation. This article uses the full solution method of harmonic response analysis, 5 groups of cutting load , which have the same phase angle and frequency and arithmetic sequential size, are input respectively. Then gets the relationship between cutting load and tangential, axial, radial maximum deformation of spindle's tool plane from the result data. As shown in Figure 3.

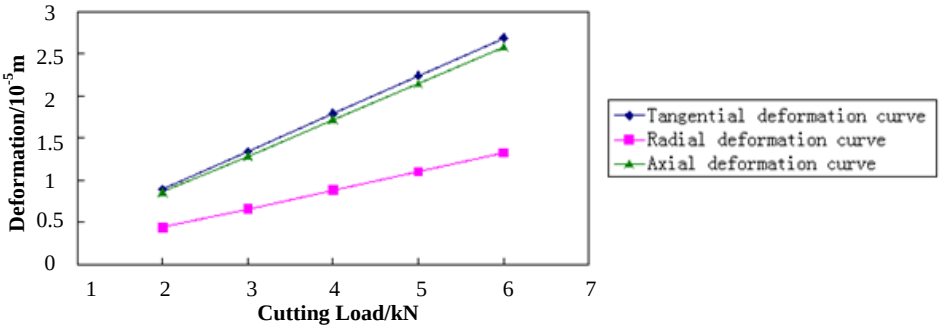

Fig. 3. Spindle's deformation curve under cutting load

From Figure 3, we can see that the spindle's maximum deformation and the cutting load are directly proportional in the working frequency range of machine. When the cutting load is bigger than a certain range, the deformation of spindle tool plane will exceed the maximum allowable deformation, and then influences the accuracy of machining. Therefore, the reliability under allowable deformation can be obtained by analyzing the spindle's deformation under cutting load. We can also see from Figure 3 that under the same size of cutting load, the spindle's tangential deformation is the largest while the axial deformation is the smallest. In consequence, this article analyzes the reliability of spindle by regarding the tangential deformation as target variable.

2. Theory of probabilistic finite element method

In the actual production process, design parameters are usually random variables, which follow some distribution, and Monte Carlo simulation technology is used to simulate this kind of problem that variety of parameters are random when massing product parts, it can clearly simulate practical problem's real characteristic [6]. Monte Carlo simulation method's basic idea as follows: Firstly, builds a stochastic model which is corresponding to the researched object, forms a random variable and its digital feature (such as probability, expectation. etc). Then in order to get plenty of random variable's sample value, a great deal of random experiments had been done. Lastly, calculates the digital feature's estimative figure by using the statistic feature [7].

Based on this idea, set the object function $U_{\max} = g(F)$, among them F is random cutting load, it subjects to a certain distribution, $U_{\max}$ is the maximum tangential deformation of spindle. Takes N times random sampling for *F*, gets N groups of sample. Then substitutes the value of i group into the object function, gets the value of $U_{\max i}(i = 1,2..n)$. Set the performance function $h(F) = U_{\max} - L$, among them L is the allowable deformation. When $h(F) > 0$, the structure is in a safe state. When $h(F) = 0$, the structure is in a limit state. When $h(F) < 0$, the structure is in a failed state. If there are N_f groups of $U_{\max}$ which made $h(F) < 0$, the probability of structural failure is:

$$P = \frac{N_f}{N} \qquad (1)$$

3. Reliability analysis of NC machine tool spindle

3.1 Reliability analysis

This stage includes: Opens the reliability analysis file, defines the distribution type and parameters that input and output variables submitted to, makes the output variables, selected analysis method, executes reliability analyze cycle [8].

Takes cutting load *F* as input variable, it submits to a Gaussian distribution whose mean value is 400N and standard deviation is 100N. Its probability distribution function is as shown in Figure 4. Takes the maximum tangential deformation on the cutting plane in the range of cutting frequency as output variable, samples 500 times by using Monte Carlo method, executes reliability analyze cycle.

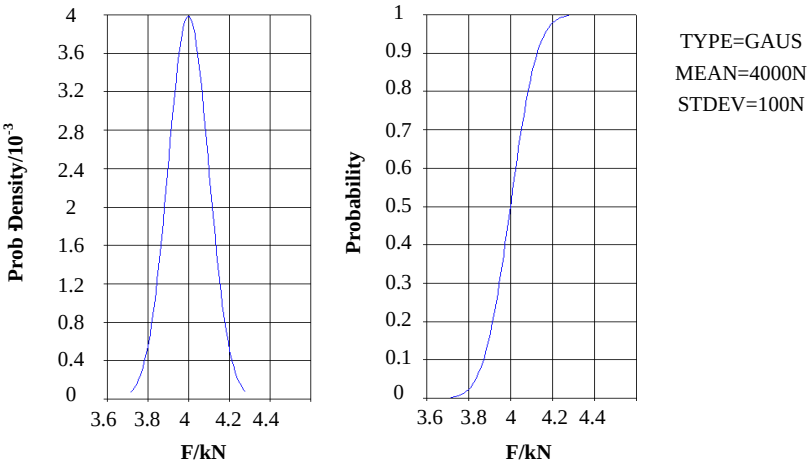

Fig. 4. Probability distribution function of cutting load

3.2 Post processing for the results

The sampling values of input variable F and output variable $U_{\max}$ gets from 500 times samplings and analysis by Monte Carlo method are as shown in Figure 5. Calculates and gets the histograms of F and $U_{\max}$ are as shown in Figure 6. We can see from the histograms that the curves are smooth, it means the sampling times are enough.

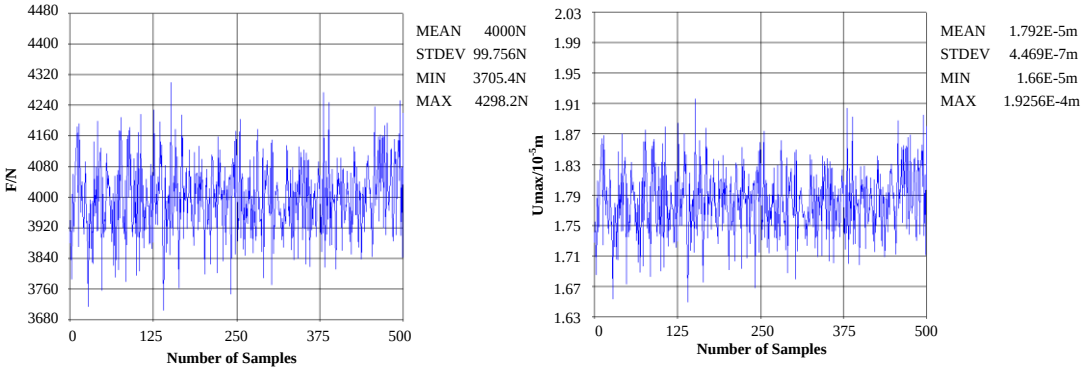

Fig. 5. Sampling values

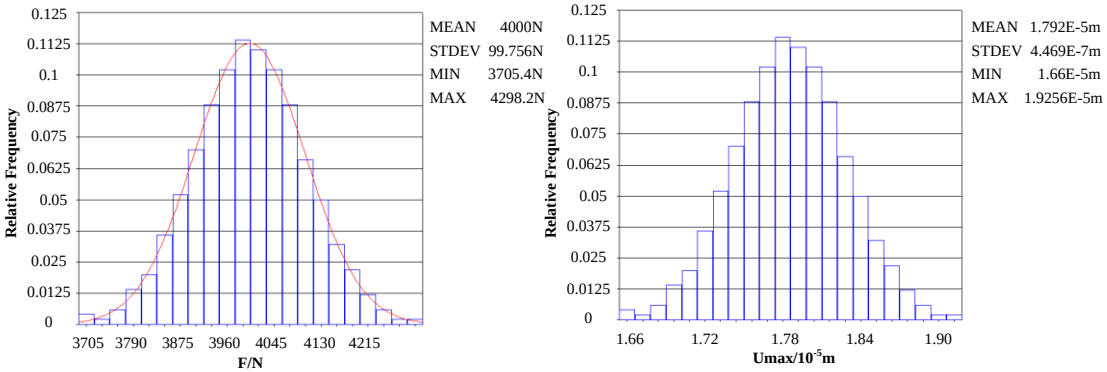

Fig. 6. Histogram

In case of setting confidence probability is 95%, the cumulative distribution curves of input variable F and output variable $U_{\max}$ can be obtained, as shown in Figure 7. On the basis of cumulative distribution curves, we can get a result that the reliability of CNC machine tool spindle under the allowable deformation

as 1.92e-5m was 98%.

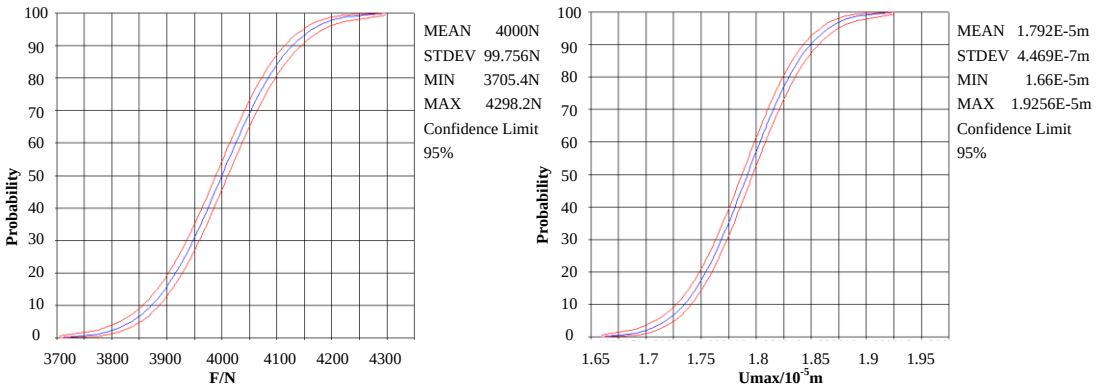

Fig. 7. Cumulative distribution curve

4. Conclusions

This article builds a CNC machine tool spindle's finite element model and analyzes its harmonic response, gets the conclusion that the spindle's maximum tangential, radial and axial deformation under cutting load are directly proportional with cutting load, and the tangential deformation is bigger than the others. On this basis, takes the cutting load as random input variables and the maximum tangential deformation as output variables, reliability analysis is finished by using probabilistic finite element method. The histograms and cumulative distribution curves of maximum tangential deformation are obtained. Then the reliability of spindle under arbitrary deformation is obtained.

Acknowledgements

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