

## Reliability Analysis on Multi-Axle Box of Dedicated Machine

Qingchen Li, Yinghua Liao, Fengjiang Li

School of Mechanical Engineering, Sichuan University of Science & Engineering, Zigong 643000, China

### Abstract

**In a dedicated machine tool, the box is one of the most important parts of the multi axle box, its deformation will directly affect the position accuracy of the parts in the multi axle box, and then affect the accuracy and reliability of the entire multi axle box. The finite element analysis of the deformation of the box is usually based on certain parameters. Considering the randomness of the modulus of elasticity, the density and the cutting force in practice, the finite element model of the box is established in the finite element analysis software ANSYS, the modulus of elasticity, the density and the cutting force are regarded as random input variable, and the maximum deformation is regarded as output variable, uses Monte Carlo method to analyze the reliability of the box, and gets the reliability of the box under allowable deformation. A feasible analysis method is provided for reliability design of box and similar parts.**

### Keywords

**box; reliability; Monte Carlo method; ANSYS**

### 1. Introduction

In a dedicated machine tool, the box is one of the most important parts of the multi axle box. The axles, bearings, bearing covers and other parts of multi axle box are respectively arranged on the box through different installation forms. The box also fixes the whole multi axle box on the machine tool bed by its own structure. The box not only transmits the force and torque between part with part, part with machined workpiece in the multi axle box, but also plays an important role in ensuring the position accuracy of each rotating axle and the relative position accuracy between rotating axle with machine tool's guide rail.

The box will deform under the action of external force, its deformation will directly affect the position accuracy of the parts in the multi axle box, and then affect the accuracy and reliability of the entire multi axle box. If the deformation of the box is too large, beyond the allowable range, it may causes the failure of the multi axle box[1][2].

The finite element analysis of the deformation of the box is usually based on the certainty parameters, that is to say, the material properties, boundary conditions, loads and other parameters are all assured. However, there are many uncertainties in these parameters, which brings some new problems to the deterministic finite element analysis. On the one hand, with the development of the finite element technology, a lot of high precision elements are put forward, which makes the calculation accuracy more and more high. On the other hand, there is a large statistical randomness in the material parameters, boundary conditions and loads, which makes the high precision of the high precision element greatly reduced due to the influence of the statistical randomness. In order to solve this problem, it is necessary to regard the material properties, loads and other uncertain factors as random variables, the carries on reliability probability analysis of box[3]. In this paper, the box of a dedicated machine tool's drilling multi axle box is taken as an example, the reliability of the box is studied by using the finite element software ANSYS.

## 2. Reliability analysis theory

For the case of the multi axle box's box, its reliability means the probability of completing the specified function under the prescribed conditions and the prescribed time interval. Its failure can be considered that the maximum deformation is more than the allowable deformation, which leads to the processing precision is not required. Failure probability  $P_f$  can be expressed as:

$$P_f = P[g(x) < 0] = \int_{g(x) < 0} f(x) < 0 dX \quad (1)$$

In the formula,  $g(x)$  is the structure's function under limit state, the random variables  $X=(X_1, X_2, \dots, X_n)$  in it express random parameters. When  $g(x)>0$ , the box is in safe condition. When  $g(x)=0$ , the box is in the limit state. When  $g(x)<0$ , the box is fail. Generally, it is difficult to directly establish the expression of  $f(x)$ . In ANSYS, the reliability of the box can be studied by Monte Carlo method[4][5].

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.

Based on this idea, set the object function  $Z=g(X_1, X_2, \dots, X_n)$ , among them  $X_i$  is random variable, it subjects to a certain distribution. Takes  $N$  times random sampling for  $X$ , gets  $N$  groups of sample. Then substitutes the value of  $j$  group into the object function, gets the value of  $Z_j$  ( $j=1,2,\dots,n$ ). If there are  $N_f$  groups of  $N$  which made  $Z_j < 0$ , the probability of structural failure is:

$$P_f = \frac{N_f}{N} \quad (2)$$

In the formula,  $N$  is the total number of samples,  $N_f$  is the number of failure.

## 3. Steps of reliability analysis

### 3.1 Build the model of box

Before using ANSYS to study the reliability of the box, we must first establish the structure model of the box, the structural model's quality will affect the efficiency and accuracy of the finite element analysis to a large extent[6]. Because the ANSYS modeling operation is very complicated, so this paper uses the three-dimensional modeling software Proe to carry on the modeling to the box, then imports the model into ANSYS. The fillet, chamfer, screw holes and other small structure will be divided into many elements when analyze in ANSYS, which will greatly increase the analysis time. The results of the finite element analysis will not produce large changes after ignoring these small features. So, in the process of building structure model, the box is simplified properly. The simplified box includes the subject box and box cover two parts. The model of subject box is shown in figure 1, the model of box cover is shown in figure 2.

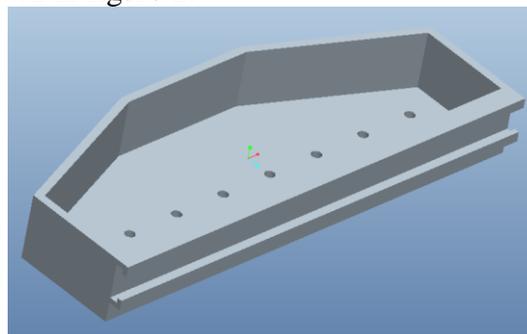


Figure 1 Model of subject box

Because the subject box and the box cover are connected by screws, there will not be relative sliding produced between them, so the two parts of the box are regarded as an integral part of the finite element analysis. The model of box is shown in figure 3.

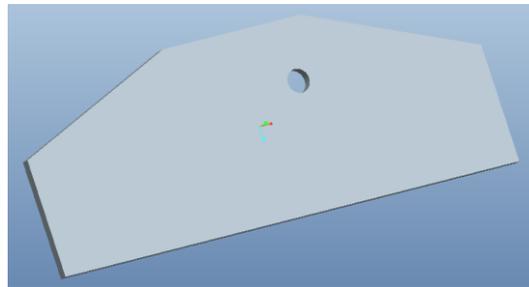


Figure 2 Model of box cover

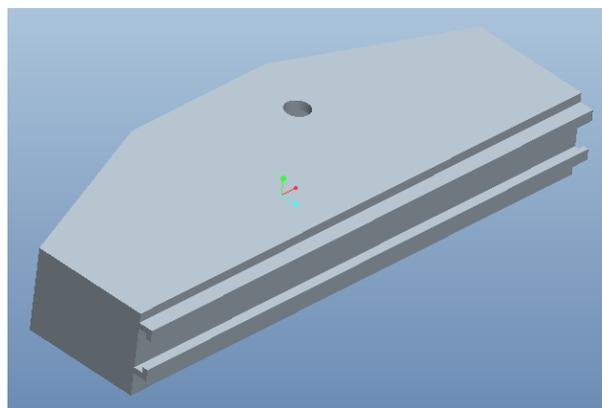


Figure 3 Box model of multi axle box

### 3.2 Perform reliability analysis

When using ANSYS reliability analysis module Prob Design to carry on the reliability analysis to the box body, the following three steps are included: generating analysis file, performing reliability analysis and dealing with results[7].

(1) Generating analysis file. Analysis file refers to the cyclic document of the reliability analysis, it needs to be written by ANSYS parametric design language APDL. The rationality of the analysis file is an important guarantee for reliability analysis's calculation efficiency and correctness of the results. The creation of analysis file contains pretreatment, solving and extraction results 3 parts.

The first step is to pre-treat the box: first, the box model is introduced, and the element type is SOLID185, the material parameter  $E=1.4e11$ , the Poisson's ratio is 0.25, the density is  $7300N/m^3$ . Then meshing the model (the element level is set to level 3). The finite element analysis model of the box is shown in Figure 4.

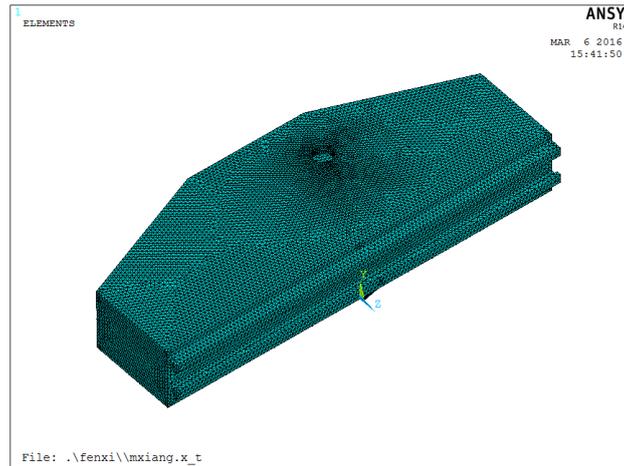


Figure 4 Finite element analysis model of box

The second step is to solve, sets full constraints to the contact surface of box and machine tool bed, sets cutting force  $F=663.8N$ , and then solves by the Solver. The third step is to extract the results, extracts the maximum deformation of the box, sets to the parameter of U.

(2) Performing reliability analysis. After entering the analysis file, you need to repeat the analysis file to achieve reliability analysis, this is the key link of reliability analysis. This stage mainly includes: the definition of input and output variables, the choice of analysis method, the implementation of the reliability cycle 3 steps.

Whether static or dynamic analysis, the material is regarded as the ideal material, and its parameters are in good accordance with the theoretical value. But in reality, there is a small difference between the materials, the material parameters can not be absolutely the same. In addition, due to the external conditions such as temperature and other factors such as cutting tool, workpiece, the size of the cutting force is also changing. So, you can specify the modulus of elasticity of the material, the density and the cutting force as random input variables, its parameters are shown in Table 1.

Table 1 Random parameters

	Distribution type	Mean value	Standard deviation
Modulus of elasticity E (Pa)	GAUSS	1.4E11	1.4E9
Density $\rho$ (N/m <sup>3</sup> )	GAUSS	7300	100
Cutting force F (N)	GAUSS	663.8	20

Next, sets the maximum deformation of the box as the output variable U.

Then selects Latin Hypecube of Monte Carlo as analysis method to sample 500 times, Performs reliability analysis.

(3) Dealing with results. When cycle completed, you can view the input and output variables' sampling value, histogram and probability cumulative curve.

#### 4. Reliability analysis's results of the box

The three input variables' statistical histograms are shown in Figure 5, 6 and 7

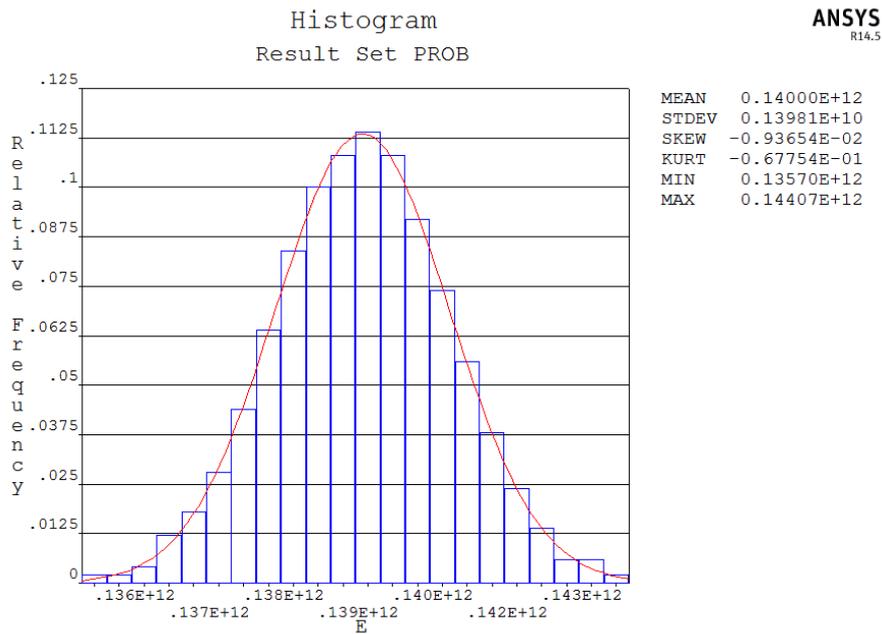


Figure 5 Histogram of elastic modulus E

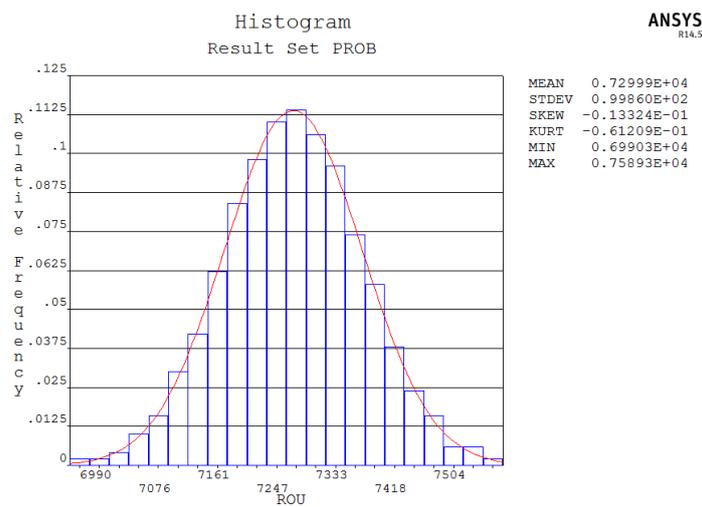


Figure 6 Histogram of density  $\rho$

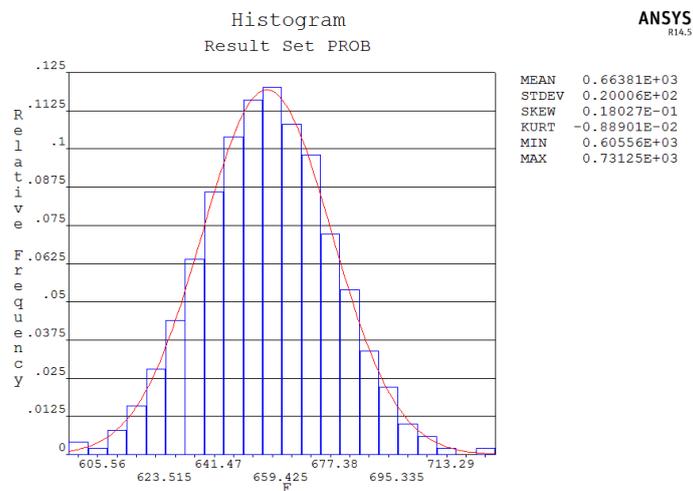


Figure 7 Histogram of cutting load F

In the figure, the horizontal coordinate indicates the value of each random variable, and the longitudinal coordinate is the relative frequency (the proportion that a value's sample number for the

total sample number). The red line is the curve that fits the frequency of each value. It can be seen from the statistical histogram that the curves of the 3 random variables are very smooth, and the shape conforms to the characteristic of GAUSS distribution, it means the sample number 500 times is sufficient.

The value of each input variable is shown in Table 2

Table 2 Value feature of input parameters

	Mean value	Standard deviation	Maximum value	Minimum value
Modulus of elasticity E (Pa)	1.4e11	1.398e9	1.44e11	1.357e11
Density $\rho$ (Kg/m <sup>3</sup> )	7299.9	99.86	7589.3	6990.3
Cutting force F (N)	663.81	20.06	731.25	605.56

It can be seen from the table that each parameter's value is very similar to the preset value, it means the value is reasonable and reliable.

Sets the confidence probability to 95%, we can get the output variable's sampling, histogram and probability cumulative curve as shown in Figure 8, 9 and 10.

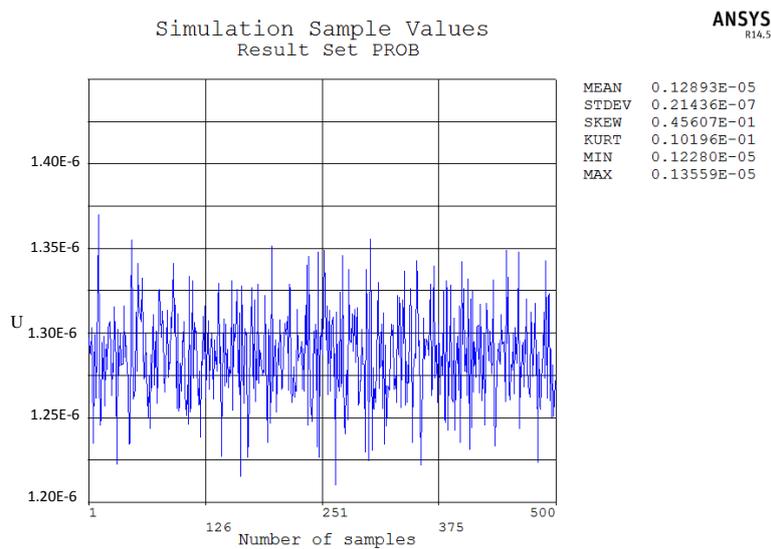


Figure 8 Sampling of output parameter U

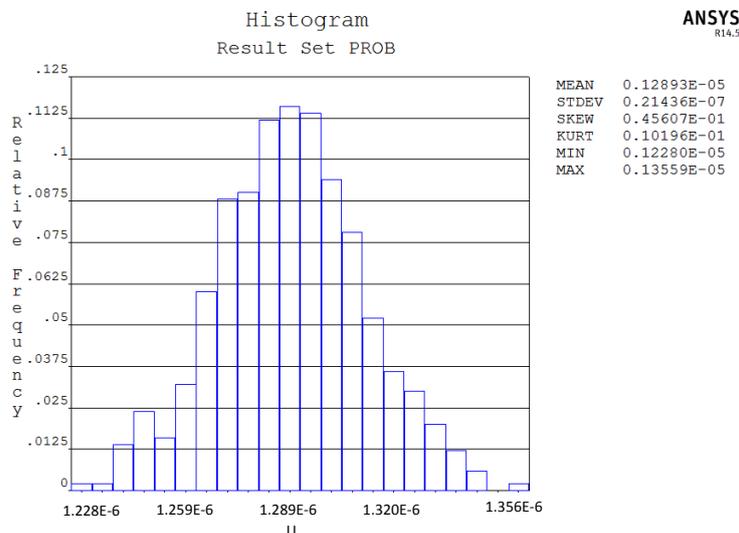


Figure 9 Histogram of output parameter U

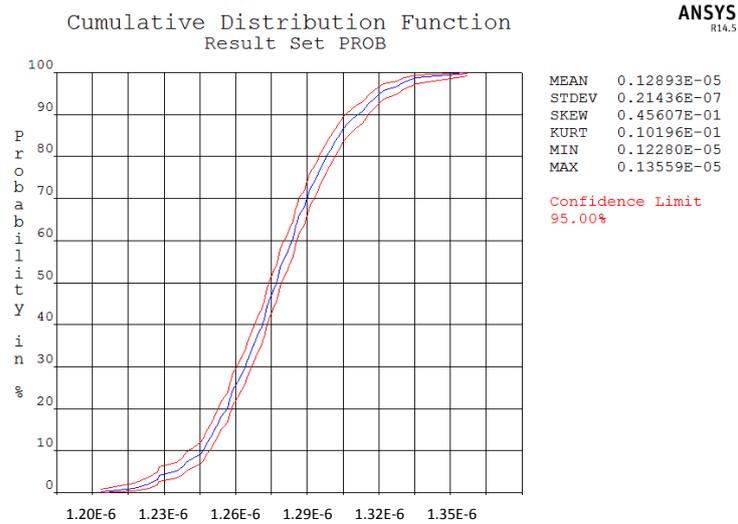


Figure 10 Probability cumulative curve of output parameter U

It can be seen from the figure that when the modulus of elasticity, density, and the value of the cutting force is no longer constant, the maximum deformation of the box U is no longer fixed, but approximate GAUSS distribution, mean value is about  $1.2893 \times 10^{-6}$ mm, standard deviation is about  $2.1436 \times 10^{-8}$ mm. In addition, we can continue to calculate the reliability of the box under a certain deformation according to the probability cumulative curve. As shown in Table 3, the reliability of the box under some typical allowable deformation is given.

Table 3 Reliability of box under typical allowable deformations

Allowable deformation (mm)	1.25e-6	1.3e-6	1.35e-6
Reliability	43.04%	69.83%	99.76%

Conversely, we can also calculate the allowable deformation under a certain reliability. For example, in order to ensure the reliability of the box is not less than 98%, the box's allowable deformation can not be less than 1.335e-6mm.

In the process of practical design and optimization, it is supposed not only to know which factors may affect the deformation, but also to understand the sensitivity of these factors to the deformation, then to determine the primary and secondary relationships to consider various factors of optimal design. Through the reliability analysis of ANSYS, these data can be clearly obtained. The sensitivity of the modulus of elasticity, density and cutting force to the deformation is shown in Figure 11.

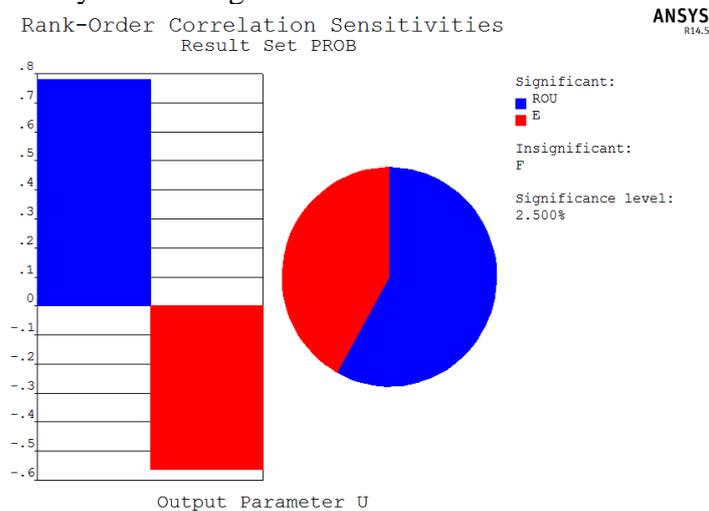


Figure 11 Sensitivity distribution map of parameters

It can be seen that in the three factors, the density of the material is the most important factor that affects the deformation of the box, followed by the modulus of elasticity, and cutting force's effect is very small. The reason for this phenomenon is that the variation range of cutting force  $F$  is small.

## 5. Conclusion

(1) When the modulus of elasticity, the density and the cutting force are used as the random input variables, the box's maximum deformation  $U$  is no longer fixed, but approximate GAUSS distribution, mean value is about  $1.2893 \times 10^{-6}$ mm, standard deviation is about  $2.1436 \times 10^{-8}$ mm.

(2) The reliability of the box under allowable deformations  $1.35 \times 10^{-6}$ mm is 99.76%. Conversely, in order to ensure the reliability of the box is not less than 98%, the box's allowable deformation can not be less than  $1.335e-6$ mm.

(3) In the three factors, the density of the material is the most important factor that affects the deformation of the box, followed by the modulus of elasticity, and cutting force's effect is very small. It is because the variation range of cutting force  $F$  is small.

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