Design and Modal Analysis of Multi-axle Box of Modular Machine Tool

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Abstract

Aiming at the problem of multi-axle box design with traditional three-layer structure, the structure layout of multi-axle box of traditional modular machine tool was studied, and a new type of multi-axle box of modular machine tool was designed. The three-dimensional model of the new multi-axle box was established by using the three-dimensional modeling software, and the modal analysis of the box was carried out by using the finite element analysis software. The results show that the new multi-axle box is lighter and more accurate than the traditional three-story multi-axle box, and the modal mode shape and natural frequency of the box can provide theoretical basis for the design and improvement of the box.

Keywords

Special machine tool; Multi-axle box; Structural design; Modal analysis.

1. Introduction

Multi-axle box is the core component of modular machine tools, which is widely used in various cutting machines [1]. Multi-axle box is mainly composed of box, spindle, transmission shaft, gear and general and special accessories. In Germany, the standard of multi-axle box was established in the early 1990s, and BOK multi-axle box based on general parts was developed. Its box structure can be composed of one, two and three layers of mechanism [2]. With the increasing requirement of chamfering processing technology for porous axle parts, the demand for multi-function, high stability and high reliability multi-axle box is increasing. Therefore, according to the layout of multi-axle box with traditional three-layer structure and the chamfering requirement of five-hole axle parts, a new chamfering machine tool multi-axle box is designed, and the modal analysis of the box body is carried out, which provides a theoretical basis for the design and optimization of multi-axle box body.

2. Research and Design of New Multi-axle Gearbox

2.1 Structural Layout Analysis of Traditional Multi-axle Box

Traditional multi-axle box mainly adopts three-layer structure, the bottom layer is oil tank, which is used to store lubricating oil, its function is heat exchange and cooling. The middle layer is the main box body, gear transmission box, distribution of transmission ratio, get the appropriate speed. The upper layer is connected to the power source, while protecting the upper structural parts. The traditional multi-axle box distributes the power and rotational speed of the drive shaft to each axle according to the design requirements through a certain transmission chain. Whether the transmission system is good or not will directly affect the quality of multi-axle box, the degree of generalization, the size of design and manufacturing workload and its cost, and the surface quality of the workpiece. The structure diagram is shown in Figure 1 below.

As can be seen from the figure above, the main problems of the three-storey multi-axle box are as follows:

(1) The transmission chain is long, the transmission relationship is complex, and the transmission error accumulates greatly, which reduces the transmission accuracy.

(2) Increasing the number of transmission shafts requires increasing the size of the box, thus increasing the weight of the multi-axle box itself, which is not conducive to the overall layout design of modular machine tools.

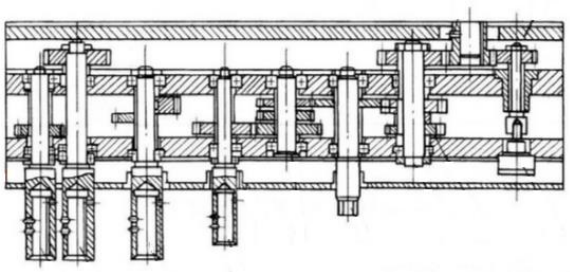


Fig. 1 Schematic diagram of three-layer multi-axle box

2.2 Design of New Type Multi-axle Box

As a whole, the new multi-axle box requires a compact layout of the axles and a reduced weight of the multi-axle box. At t same time, a new structure of the multi-axle box body is adopted to facilitate the replacement of lubricant and cooling oil and maintenance. The overall layout of the new multi-axle box designed in accordance with the technical requirements is shown in Figure 2 below.

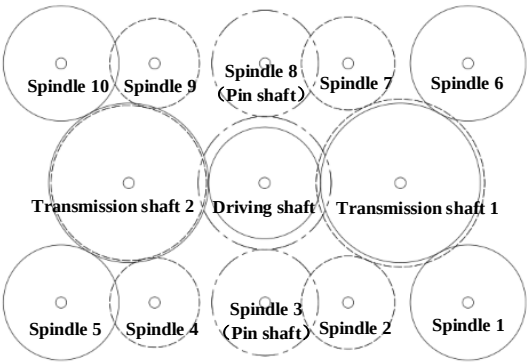


Fig. 2 Overall layout of the new multi-axle box

There are many spindles in the multi-axle box, three-row gear transmission is used to improve the compactness of the multi-axle box. One pin is added between the first and fifth axes, another pin is machined between the sixth and tenth axes, the three middle axes are the driving axle and the transmission axle respectively, the driving axle is on the straight line of the vertical bisection of the two outermost holes of the pin, ensuring that the maximum cutting force in cutting engineering is equal in size and opposite in direction. The two-dimensional assembly diagram of the new multi-axle box is shown in Figure 3 below.

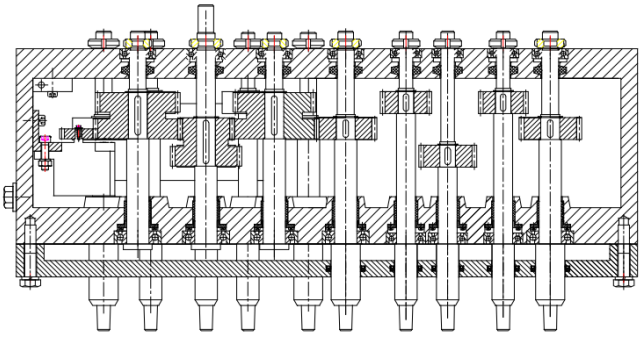


Fig. 3 Two-dimensional assembly drawings of new multi-axle box

As can be seen from the figure above, the main advantages of the new multi-axle box are as follows:

(1) The traditional three-layer structure is changed into a two-layer structure, which reduces the length of the transmission chain and improves the transmission precision.

(2) The symmetrical structure is adopted, the layout of the transmission shaft is more compact, the weight of the box is reduced, and the lightweight design is realized.

(3) The symmetrical pin ensures the consistency of transmission speed and is beneficial to speed control of transmission shaft.

3. Modal analysis of a new type of multi-axle box

The accuracy of multi-axle box is affected by many factors, the box of multi-axle box is a multi-degree-of-freedom elastic vibration system, its dynamic characteristics directly affect the accuracy of multi-axle box, thus affecting the accuracy of modular machine tools as a whole [3]. The box is subject to the excitation of multiple excitation sources, which mainly include two categories [4]: ① Meshing excitation of inter-shaft transmission gear pair in multi-axle box. ② Vibration excitation also occurs in the operation of modular machine tools. According to the theory of machine tool resonance, when the frequency of machine tool excitation source is close to the natural frequency of multi-axle box, it will cause resonance of machine tool multi-axle box, which is easy to cause greater damage [5]. Therefore, the working frequency of multi-axle box should be far away from the inherent low-order frequency. Meanwhile, it is necessary to conduct modal analysis of the new symmetrical multi-axle box, which provides theoretical guidance for the design of multi-axle box and lays a foundation for the study of the dynamic characteristics of the new multi-axle box system.

3.1 Modal analysis theory of box

The purpose of modal analysis is to obtain the natural frequencies and modes of the box, which can be used to analyze the dynamic characteristics of the box. Based on classical mechanics theory, the differential equation of modal analysis of box body is:

$$[M]\{\ddot{x}\} + [C]\{\dot{x}\} + [k]\{x\} = \{f(t)\} \quad (1)$$

In the formula, $[M]$ is the mass matrix, $[C]$ is the damping matrix, $[k]$ is the stiffness matrix, $f(t)$ is the load matrix, $\{\ddot{x}\}$ and $\{\dot{x}\}$ are the acceleration and velocity of the box in the integral coordinate system, respectively.

In the modal analysis of the box, the load matrix $f(t)=0$, and the damping term can be neglected because the damping has little effect on the natural frequencies and modes of the box structure [6].Then a new equation is obtained:

$$[M]\{\ddot{x}\} + [k]\{x\} = \{0\} \quad (2)$$

Its characteristic equation is:

$$([k] - \omega^2[M])\{x\} = \{0\} \quad (3)$$

In the formula, ω is the natural frequency of the box.

By solving the characteristic equation (3), the natural frequency ω and main mode $\{x\}$ of the box can be obtained.

3.2 Establishment of finite element model for modal analysis of box

Modeling software is used to import the built box model into Abaqus software, as shown in figure 4, to complete pre-processing, simulation calculation and other steps. Model parameters are shown in table 1 below.

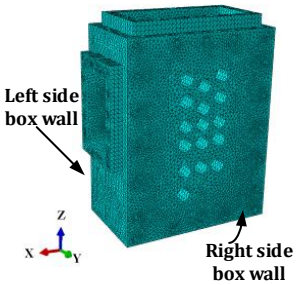


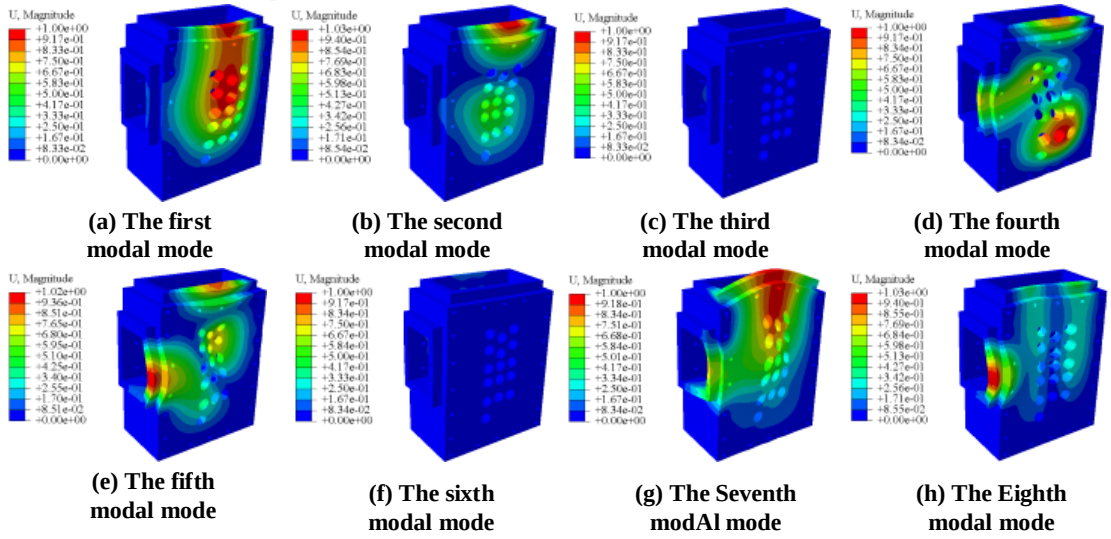
Fig. 3 Box finite element model

Table 1 Finite element model parameters of box

Name of material	Density /(kg/m3)	Elasticity modulus E /(N/m2)	Poisson's ratio	Total number of nodes	Total number of elements	Elements type
HT350	7.30E+3	1.45E+11	0.27	509724	343106	C3D10

3.3 Modal analysis results of multi-axle box

The first eight modes of the box are obtained by post-processing of Abaqus software as shown in Figure5, and the natural frequencies and modes are analyzed as shown in Table 2.



(a) The first modal mode (b) The second modal mode (c) The third modal mode (d) The fourth modal mode

(e) The fifth modal mode (f) The sixth modal mode (g) The Seventh modAl mode (h) The Eighth modal mode

Fig. 4 Modal diagram of multi-axle box

Table 2 Natural frequency and mode analysis

Modal order	Natural frequency /Hz	Mode of vibration
1	1797.6	The right side of the box wall is distorted along the Y-axis
2	2237.6	Distortion of the right side of the box wall along the Y-axis
3	2317.4	The left side of the box wall is distorted along the Y-axis
4	3279.7	Distortion of the right side of the box wall along the Y-axis
5	3563.5	Distortion of the right side of the box wall along the Y-axis
6	3587.2	The left side of the box wall is distorted along the Y-axis
7	4242.9	The right side of the box wall is distorted along the Z-axis
8	4335.5	Distortion of the right side of the box wall around the Z-axis

4. Conclusion

Through the study of multi-axle box of traditional modular machine tools, the overall design of new multi-axle box and the modal analysis of the box, the following conclusions are drawn:

(1) Aiming at the traditional three-layer structure of multi-axle box, the new multi-axle box transmission shaft has more compact spatial layout, less material consumption and less weight, which is beneficial to the overall lightweight design of multi-axle box.

(2) From the modal analysis of the new multi-axle box, it can be seen that large deformation occurs on both sides of the box wall and at the opening of the box body in the second and fifth modes. The working frequency of the box body should be far away from the two natural frequencies of 2237.6 Hz and 3563.5 Hz.

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