An improved technique of clamping method for keeping coaxiality precision of rotating frame

Long Wu, A M Wang*, P H Ren, and D X Li

School of Mechanical Engineering, Beijing Institute of Technology, Beijing, 100081, China

Abstract. In order to ensure the concentricity accuracy of frame-like thin-walled parts, this paper takes the rotating frame as a machining example. And using the method of finite element simulation and calculation, this paper analyzes the main factors that cause the error of coaxiality of the rotating frame. Because the clamping force of the clamping device causes the deformation of the workpiece, this article is based on the finite element simulation to improve the clamping method. By adding a fixing block at the bottom of the frame and clamping with the fixing block to avoid direct pressure on the rotating frame, the error of frame concentricity caused by the clamping deformation is reduced in this way. Aiming at the error caused by machine error, this paper improves the clamping device and adds the calibration mechanism to correct the machine error and ensure the coaxial accuracy. Through the application of the improved method proposed in this paper, the concentricity error of the rotating frame can be guaranteed within 0-0.005mm.

1 Introduction

Rotating frame is an important part of the air defense missile servo system, belonging to the framework of high-strength aluminum alloy thin-walled parts. In addition to the common problems in the processing of aluminum alloy thin-walled parts, such as poor rigidity and clamping difficulties, etc., this part also has the following characteristics: (1) Holes with high concentricity and perpendicularity of intersection; (2) Holes with large size and roundness requirements [1-3]. In high volume production, the main processing method is the use of boring mold tooling [4-5]. In low-volume production, the main machining methods are the boring method using longer shanks and the method of rotary boring [6-9]. In this paper, the rotating frame, shaft and hole have coaxial requirements, only rotary boring process is suitable. Therefore, this article mainly analyzes the error reduction of rotary boring process. Caused by the coaxial rotation frame error factor, mainly consists of two parts: one is the error caused by clamping deformation; the other one is the machining error caused by machine accuracy.

In order to ensure the concentricity accuracy of frame-like thin-walled parts, this paper takes the rotating frame as a machining example. And using the finite element simulation, this paper analyzes the main factors that cause the error of coaxiality of the rotating frame. Because the clamping force of the clamping device causes the deformation of the

* Corresponding author: wangam@bit.edu

workpiece, this article is based on the finite element simulation to improve the clamping method. By adding a fixing block at the bottom of the frame and clamping with the fixing block to avoid direct pressure on the rotating frame, the error of frame concentricity caused by the clamping deformation is reduced in this way. Aiming at the error caused by machine error, this paper improves the clamping device and adds the calibration mechanism to correct the machine error and ensure the coaxial accuracy. Through the application of the improved method proposed in this paper, the concentricity error of the rotating frame can be guaranteed to be within 0-0.005mm.

2 Folder deformation analysis

Rotating frame belongs to the framework of thin-walled parts. The material is cast aluminum and of hollow structure. The smallest wall thickness is only 1.8mm and hence the parts stiffness is weak. The coaxiality of the front axle and tail hole must be within 0-0.005mm.

Fig. 1. Fix the edges of the frame.

Fig. 2. Fix the middle of the frame.

Clamping deformation is an important reason for the error of coaxiality. To improve the clamping process, we do the finite element simulation and the simulation results are the basis for optimizing the clamping device. As shown in figure 1 and figure 2, the main clamping method is divided into two kinds: (1) fixed edge and (2) fixed in the middle.

Finite element simulation is now used to analyze the deformation of the clamping and cutting deformation.

Fig. 3. Edge clamping deformation.

Fig. 4. Central clamping deformation.

As shown in figure 3 and figure 4, the simulation of the deformation by the finite element method is carried out with the edge clamp and the central clamp. The output deformation of the front clamp of the shaft is: edge clamping deformation is 5.43×10^{-11} m and central clamping deformation is 1.317×10^{-11} m.

Fig. 5. Axis boring simulation.

Fig. 6. Cutting force simulation data.

Take the boring process parameters and tool parameters into the ADVANTEDGE software for simulation analysis of the boring process of the shaft, as shown in figure 5 figure 6. The cutting force data were obtained through simulation. Taking the average value of each cutting force as the cutting force, the radial load was 8N, the tangential load was 6.8N and the axial load was almost 0 N.

Fig. 7. Edge clamping cutting deformation.

Fig. 8. Central clamping cutting deformation.

Figure 7 shows the cutting deformation analysis for the use of edge clamping method with the front axle under radial load. Figure 8 shows the cutting deformation analysis for the use of the central clamping with the front of the shaft by the radial cutting load. The amount of output shaft cutting deformation of the front is 9.83×10^{-6} m for edge clamping deformation and 1.405×10^{-5} m for central clamping deformation.

From the simulation results we can see that using the edge clamping method, the workpiece clamping deformation is large, but the deformation caused by cutting is small. It has a large workpiece stiffness. With the central clamping method, the clamping deformation is small, but the cutting deformation is so big. The stiffness is too small. Neither way guarantees a high degree of concentricity.

Fig. 9. Fixed block clamping method.

Fig. 10. Fixed block clamping deformation.

Fig. 11. Fixed block clamping cutting deformation.

As shown in figure 9, according to the analysis, four process bosses are added at the bottom of the rotating frame to fix the frame. The workpiece clamping deformation and cutting deformation is analyzed, with this new way of clamping, as shown in figure 10 and

figure 11. The amount of output shaft cutting deformation of the front is 3.77×10^{-12} m for edge clamping deformation and 1.14×10^{-5} m for central clamping deformation.

Fig. 12. Frame deformation under different fixed modes.

Fig. 13. Cutting deformation of frame under different fixed modes.

As shown in figure 12 and figure 13, a histogram of the three methods of clamping is drawn from the above-described clamping deformation and cutting deformation data. The histogram analysis shows that the improved fixed block clamping method does not directly exert force on the frame and yields the smallest clamping deformation, moderate stiffness and can ensure higher machining accuracy.

3 Machine error analysis

From the nature of rotary boring, it can be seen that the concentricity of boring long holes is the key precision of rotary boring among the precision required after hole boring. Among the many error factors that affect the concentricity of rotary boring, the impact of machine-related accuracy is either major or even decisive. The main factor that forms the error of coaxiality of rotary boring includes two parts: (1) error of machine tool rotation accuracy (2) position error of machine tool during processing.

3.1 Coincidence Error Analysis Caused by Slewing Error

When boring two holes with concentricity requirements, the workbench should be rotated 180 ° after the first hole is machined. In this case, the positioning error of the worktable is transmitted to the second hole, which is a key factor affecting the coaxiality of the hole. Direct use of table rotation accuracy is difficult to ensure the concentricity of parts rotary processing. Positioning accuracy of the rotary table boring machine is limited.

Fig. 14. Relationship between slewing accuracy and concentricity.

Fig. 15. Relationship between motion accuracy and concentricity.

As shown in figure 14, if the table rotation accuracy is x and the two-hole span is L (mm), then the concentricity error due to the table rotation accuracy is

$$\Delta_1 = 2d_1 = 2 \times \frac{L}{2} \times \sin(x) \tag{1}$$

The formula shows that when the machine tool rotation error x is constant, the error increases with the increase of the span L . For example, when the span is 200mm and the swivel error is 2", the concentricity error is $2\mu\text{m}$.

For the vertical error, due to the need to rotate the workpiece several times, the cumulative rotation angle error will be greater.

3.2 The impact of exercise accuracy

Turn the boring, boring the hole before the table after the rotation of 180° (set no rotary positioning error), the table should also be traversed a fixed value, so that the boring axis and the re-boring spindle axis coincide. The horizontal value L_2 should be $2L_1$ but the actual $L_2 \neq 2L_1$. As shown in figure 15, the concentricity error caused by the motion accuracy is:

$$\Delta_2 = 2d_2 \tag{2}$$

4 Fixture installation improvements

In order to ensure the machining accuracy, the rotating frame clamping method is improved, and the rotary precision correction device is installed as shown in the figure 16.

As shown in the figure 16, the new fixture includes the following components: a Workpiece fixing block (2) for fixing the rotating frame (1), and the calibration device is fixed on the workbench by the pressure plate (3) and the support blocks (4, 6). The deflection angle of the calibration plane (5.1) of the calibration block (5) can be fine-tuned by the adjustment screw (7).

Fig. 16. Schematic of the clamping device.

After the rotating frame (1) has been clamped and positioned, milling the calibration plane (5.1) and the center hole (1.3) once, using the milled plane and hole as the angle and position calibration reference. This method can improve the relative position accuracy between the calibration device and the rotating frame, thereby improving the machining accuracy. After each stage is rotated, calibrate the angle error and the position error with the calibration plane (5.1) and the center hole (1.3). Eliminate oversize of machined parts due to accumulated errors during table rotation.

5 Conclusion

In order to ensure the concentricity accuracy of frame-like thin-walled parts, this paper takes the rotating frame as a machining example. And using the method of finite element simulation and calculation, this paper analyzes the main factors that cause the error of coaxiality of the rotating frame. Because the clamping force of the clamping device causes the deformation of the workpiece, this article is based on the finite element simulation to improve the clamping method. By adding a fixing block at the bottom of the frame and clamping with the fixing block to avoid direct pressure on the rotating frame, the error of frame concentricity caused by the clamping deformation is reduced in this way. Aiming at the error caused by machine error, this paper improves the clamping device and adds the calibration mechanism to correct the machine error and ensure the coaxial accuracy. Through the application of the improved method proposed in this paper, the concentricity error of the rotating frame can be guaranteed to be within 0-0.005mm.

References

1. Wei Yu and Wang X W 2007 *J. IJAMT* (Springer International Publishing) (2007)33 p260
2. Liu H B, Hou B and Zhang J 2015 *M. Intelligent Robotics and Applications*. (Springer International Publishing) p:701-709.
3. Izamshah R A, Mo, John, Ding and Song Lin. 2011 *J. Key Engineering Materials*, 458(458):p 283-288.
4. Iwabe H, Shimada T and Yokoyama K. 1997 *J. Transactions of the Japan Society of Mechanical Engineers*, 63(605) p239.
5. Jer-Shyong Tsai and Chung L L 1998 *J. Journal of Materials Processing Technology*, 94 p235
6. Gao S, Yong-Liang A N. 2014 Study on Precision of Thin-Wall Parts CNC Milling *J. Machinery Design & Manufacture*.
7. Chen Z S, Xiao-Mei S I, Liu D X. 2012 *J. Aviation Precision Manufacturing Technology*, 2012., 63(605) p239.
8. Song L, Yonggang W U. 2013 *J. Machine Tool & Hydraulics*, 2013(16) p322.
9. Xiaoming Huang and Jie Sun 2015 *J. IJAMT* (Springer International Publishing) 77:1035–1041