Optimization of High-speed and High-precision Turntable Drive Structure for Five-Axis Blade Machine Tool

Fengkui Xiong [1, a], Kang Liu [1, 2, b], Ming Zhang [3, c]

[1]Sichuan University of Science & Engineering, Zigong Sichuan 643000, China;

[2]Sichuan Provincial Key Lab of Process Equipment and Control, Zigong Sichuan 643000, China.

[3] Mianyang Vocational and Technical College, Mianyang Sichuan 621000, China.

[a]xfk763101899@126.com, [b] 315381847 @qq.com, [c] zhangm123333@163.com

Abstract

This paper introduces several classic turntables, and summarizes its advantages and disadvantages, and then innovates a new type of high-speed and high-precision turntable for five-axis blade processing machines. The utility model adopts a double helical gear forward and reverse anti-backlash mechanism to eliminate the forward and reverse switching gap of the gear transmission, and at the same time, combined with a high-precision angle encoder, the transmission precision of the rotary mechanism is greatly improved; The compact disc spring automatic compensation mechanism automatically compensates for the gap formed after the gear wears, making the gear transmission accuracy more stable; Two-stage helical gear transmission enables the turret to transmit high torque at a higher speed.

Keywords

Aero engine blade; High-speed high-precision turntable; Double helical gear backlash; Disc spring automatic error compensation.

1. Foreword

As the heart of the aircraft, the aero engine is known as the "flower of industry" and is a symbol of national science, industry and national defense. However, the blade is the most critical and core component of the aero engine, which greatly determines the performance of the aero engine[1] . In order to meet the high reliability, long life and high performance requirements of aerospace engines in harsh working environments, the blades must have precise dimensions, accurate shape and structure, high surface quality and temperature, high pressure and centrifugal tremor environment, Excellent mechanical properties and stability.

To meet such high processing requirements, the processing accuracy of the machining equipment, the five-axis blade machining machine, is extremely high. The direct impact of the performance of the CNC turntable even determines the stability and accuracy of the machine[1]. The turntable of the five-axis blade machining machine must have high rigidity, high torque, high speed and high precision, and good precision and stability. The ordinary turntable has low torque, slow response, and poor wear resistance, which cannot meet the requirements[2].

Therefore, based on the introduction of several classic turntables, this paper introduces a new type of high-speed and high-precision turntable for five-axis blade processing machine based on double helical gear backlash and disc spring automatic compensation mechanism.

FIG.1 CNC rotary table (a axis) schematic

FIG.1 Spindle swing five-axis blade machining center

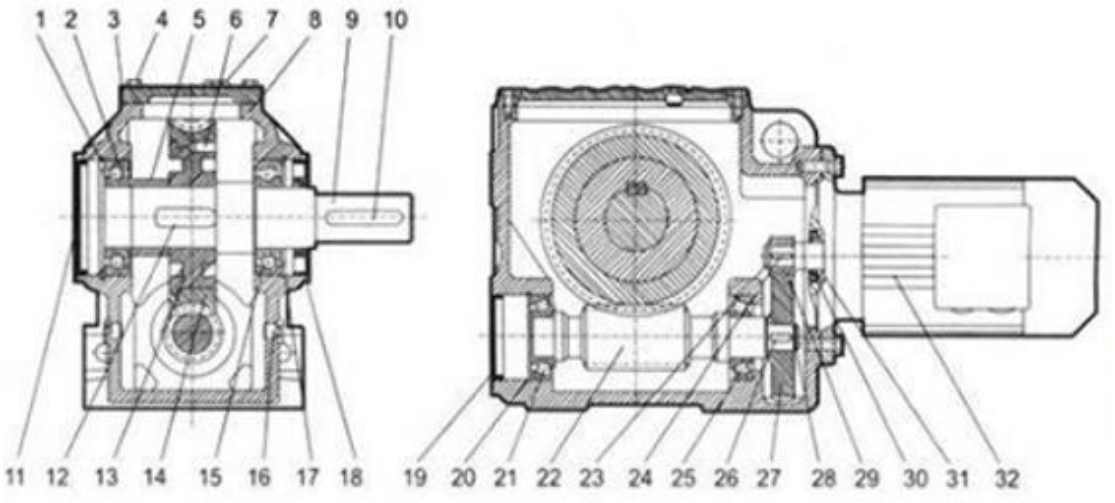
2. Overview of common CNC turntables

The CNC rotary table is one of the core components of the five-axis linkage machine. It not only provides high-precision indexing function for the rotary axis (a-axis) of the five-axis linkage machine, but also with the Cartesian coordinates (X, Y, Z) axes. Accurate linkage, the rotary feed motion, together with the Cartesian coordinate axis to complete the processing of complex parts such as aero-engine blades[5]. Because of its control system structure, there are nonlinear links such as friction torque, gap error of multi-stage gear transmission, and thermal error during transmission. As a result, the smoothness and accuracy of the transmission are difficult to meet the requirements of blade machining. Therefore, it is extremely urgent to eliminate the key nonlinear factors in the CNC turntable and improve the motion accuracy and dynamic response characteristics of the turntable[6]. The thermal error generated during the transmission process can be compensated by the numerical control system (SIEMENS 840D), so the accumulated error of the transmission gap of the transmission mechanism is the key factor affecting the transmission precision and the smoothness of the transmission. Below I will introduce several classic CNC turntables.

At present, the common turret transmission anti-backlash mechanism is divided into two types: a helical gear transmission anti-backlash mechanism and a worm gear transmission anti-backlash mechanism[3].

The common worm and worm gear transmission mechanism is the most commonly used transmission mechanism of the CNC rotary table. It only completes the specified angular positioning of the workpiece. In addition to the indexing and indexing function, the CNC rotary table also needs to be able to complete the rotary feed motion in conjunction with the Cartesian coordinate axis. However, the adjustment of the backlash of the ordinary worm-gear turret is usually only 0.03-0.08mm, which obviously cannot meet the design requirements of the high-precision turret, and the large positive and negative reversal gap of the turret during the forward-reverse switching process. It greatly affects the indexing accuracy and the rotary feed response speed of the turntable[3].

2.1 Traditional worm gear turntable

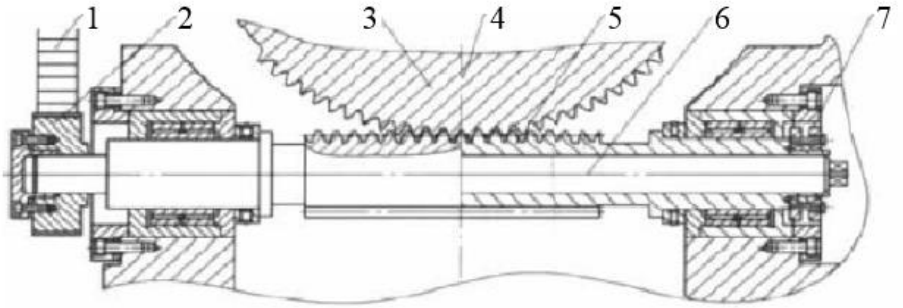


1.17.23.28-Retaining ring; 2.15.21.25.31-Bearing; 3.11.19-cover; 4-bolt; 5-Bushing; 6-Screw; 7-Vent cap; 8-Box; 9-Output shaft;10.12.24.26-Flat key; 13-Turbine mandrel; 14-Turbine rim; 16-Oil mirror;18.30-Oil seal; 22-Worm; 27.29-gear; 32-Motor

FIG.4 Traditional worm gear turret structure

2.2 Two-stage worm and worm gear anti-backlash turntable

The two-stage worm and worm gear anti-gap turntable is a turntable that is improved on the basis of the conventional worm-turbine turntable to eliminate the transmission gap.



1-Toothed belt; 2-Toothed pulley; 3-turbine;4-Contact center; 5-Hollow worm; 6-Worm shaft; 7-Expansion sleeve

FIG.4 Two-stage worm gear worm gear anti-backlash diagram

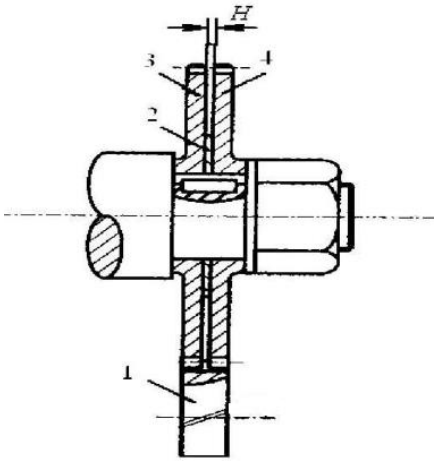
As shown in Fig. 4, this mechanism is a anti-backlash mechanism of the two-stage worm and worm gear turntable, in which the gear transmission between the motor and the worm is changed to the synchronous belt transmission in order to reduce the shock shock. The mechanism is composed of a hollow worm and a worm shaft connected by an expansion sleeve. The angle of the assembled rotary hollow worm and the worm shaft ensures that the worm turbine meshes tightly and then locks the expansion sleeve. When the mechanism wears for a long time, the expansion sleeve is released. Rotate and adjust the hollow worm and the worm shaft to ensure the mechanism is tightly engaged[4].

Advantages: self-locking characteristics, safe and reliable, compact structure, good versatility suitable for small workpiece processing.

Disadvantages: high cost, low transmission efficiency, can not eliminate the positive and negative switching gap, the heat production is large, the thermal error accumulation is serious and the maximum speed can only reach 25r/min.

2.3 Single helical gear turntable

Compared with the spur gear transmission, the helical gear transmission has the advantages of good meshing performance, small number of teeth without cutting, large overlap, compact structure, stable transmission, low noise, etc., so it is often used as the transmission mechanism of the turntable. The single helical gear washer adjusts the turntable, which is the most common single helical gear turntable with anti-backlash mechanism.



1, 3, 4: helical gear 2: Adjusting washer

FIG.5 Helical washer adjustment mechanism

As shown in Figure 5: B3+B4+H=B1 (where B is the tooth width). The gears 3, 4 are mounted together and machined with a guide flat key and can be meshed with the gear 1 at the same time. At the same time, the adjusting pad 2 of thickness H is inserted between 3 and 4, so that the spiral lines of the gears 3 and 4 are misaligned, and the left tooth surface of the gear 4 and the right tooth surface of the test 3 are respectively meshed on the tooth surface of the gear 1. To achieve backlash. The relationship between the flank clearance Δ, the adjustment pad thickness H and the helical gear helix angle α is as follows[8]:

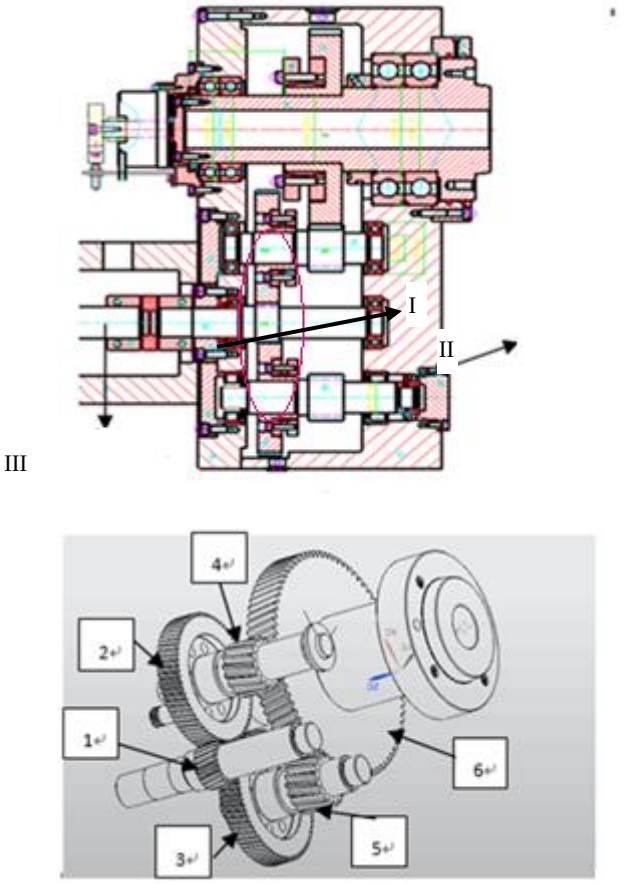
$$H=\Delta\cos\alpha \quad (1)$$

Advantages: simple structure and low manufacturing cost.

Disadvantages: The adjustment is complicated (repetitive grinding is required to ensure H=Δ cosα), automatic backlash cannot be realized, and the transmission torque is small[9].

3. Overview of common CNC turntables

Comprehensively comparing the principle and characteristics of the above-mentioned turntable, a high-speed and high-precision turntable based on the double-reverse gear forward and reverse backlash and the disc spring automatic compensation mechanism is innovated. It adopts a high-torque servo motor and is driven by a two-stage helical gear reducer to ensure high torque and high responsiveness. At the same time, it combines a dual gear anti-backlash mechanism, a disc spring automatic compensation mechanism and a high-precision angle encoder. The turntable has both high speed, high response, high rotation precision and repeated positioning accuracy, and its structure is shown in Figure 6.



I-Double helical gear anti-backlash mechanism; II-Rehmannia automatic compensation mechanism;III-Input shaft

FIG.6 New turntable structure

As shown in FIG. 7, the relative angles of the rotating driven gear 2 and the intermediate gear shaft 4 during assembly are such that the reverse working tooth surface of the output gear 6 meshes with the reverse working tooth surface of the intermediate gear shaft 4, and the driven gear 2 The positive working tooth surface meshes with the positive working tooth surface of the main transmission gear shaft 1; when the main transmission gear shaft 1 rotates clockwise, the positive working tooth surface of the main transmission gear shaft and the driven gear 2 are positively operated. The tooth surfaces are meshed to drive the driven gear 2 and the coaxial intermediate gear shaft 4 to rotate counterclockwise, and the reverse working tooth surface of the intermediate gear shaft 4 meshes with the reverse working tooth surface of the output gear 6 to drive the output gear 6 to rotate clockwise. The sports relationship is shown in Figure 7 below.

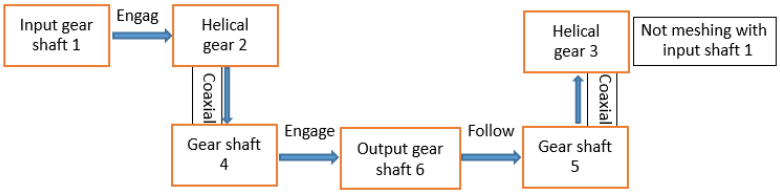


FIG.7

When the main transmission gear shaft 1 rotates counterclockwise, the reverse working tooth surface of the main transmission gear shaft 1 meshes with the reverse working tooth surface of the driven gear 3, and drives the driven gear and the coaxial intermediate gear shaft 5 clockwise. Rotation, the positive working tooth surface of the intermediate gear shaft 5 meshes with the positive working tooth surface of the output gear 6, and drives the output gear 6 to rotate counterclockwise. The motion relationship is as shown in Figure 8 below.

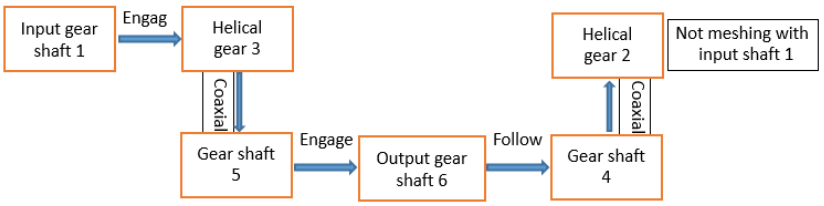


FIG.8

Since the main transmission gear shaft 1 rotates positively and negatively, the gears 2, 3 are respectively meshed with the positive and negative surfaces of the gear 1 tooth, and the gear 6 is also meshed with the opposite and positive working tooth surfaces of the gears 4 and 5, respectively, eliminating the deceleration. When the machine is reversing, the forward and reverse clearance of the gear transmission improves the accuracy of the rotary motion of the rotary table and the response speed of the forward and reverse switching, and at the same time reduces the impact of the gear transmission and increases the smoothness of the transmission.

The disc spring automatic compensation mechanism applies a reasonable preload force to the gear shaft 4 through the disc spring to compensate the synchronous wear of the pair of 4 and 2 and 6 pairs of helical gears in the transmission system under long-term operation. The resulting wear gap ultimately achieves the goal of eliminating transmission errors in the transmission system due to tooth surface wear.

4. Conclusion

The high-speed and high-precision turntable of the new five-axis blade processing machine adopts high-torque servo motor, double helical gear elimination positive and negative reversing gap mechanism, disc spring automatic compensation wear error mechanism and high-precision angle encoder to ensure the high rotation of the turntable. Accuracy, high repeatability, high speed, high torque and high stability are both excellent, which meets the extremely high processing requirements of the airborne blades.

Acknowledgements

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