

Analysis of Eliminating the Positive and Negative Clearance Mechanism of CNC Machine Tool Turntable

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Abstract: CNC machine tool turntable is the core component of multi-axis CNC machine tools, and its accuracy is an important guarantee for the overall accuracy of multi-axis CNC machine tools. This paper introduces the common rotary table and its common typical anti-backlash structure, and analyzes and compares the principle and characteristics of each structure in detail, which provides reference for the optimization design of CNC machine tool turntable.

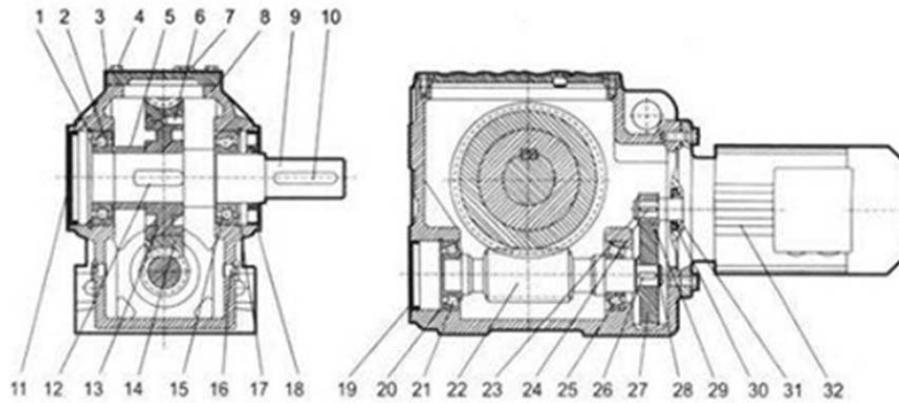
Keywords: Machine tool turntable; worm gear; helical gear; Eliminate gaps.

1. INTRODUCTION

The rotary table is one of the indispensable important functions of the multi-axis CNC machining center. It not only provides high-precision indexing function for the rotary axis (a-axis) of the multi-axis linkage machine, but also with the Cartesian coordinates (X, The Y and Z) axes are accurately linked to perform the rotary feed motion, and the rectangular coordinate axes cooperate to complete the processing of complex parts in space.

At present, the transmission structure commonly used in turntables is divided into three types: worm gear drive, helical gear drive and torque motor [1]. Although the torque motor has no intermediate transmission link, the transmission accuracy and response speed are high, but its torque is small and the shock resistance is poor, which cannot meet the requirements of high rigidity and high torque processing. In addition to the two typical transmission structures, there is a backlash, and the backlash is the main factor affecting the positioning error of the rotary table of the machine tool. How to eliminate the backlash to the utmost is a key issue that designers need to consider. In this paper, two typical transmission structures are analyzed and compared in detail from the principle and characteristics, which provides reference for the optimization design of CNC machine tool turntable [2].

2. TURBINE WORM DRIVE STRUCTURE TURTABLE



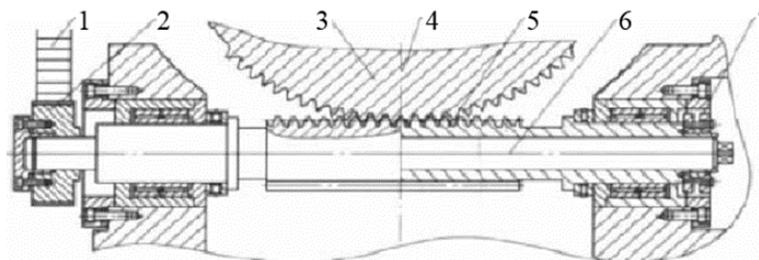
1.17.23.28-Retaining ring; 2.15.21.25.31-Bearing; 3.11.19-cover; 4-bolt; 5-Bushing; 6-Screw; 7-Vent cap; 8-Box; 9-Output shaft;10.12.24.26-Flat key; 13-Turbine mandrel; 14-Turbine rim; 16-Oil mirror;18.30-Oil seal; 22-Worm; 27.29-gear; 32-Motor

Fig 1. Traditional worm gear turret structure

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 work piece. 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 Two-stage worm and worm gear anti-backlash structure

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

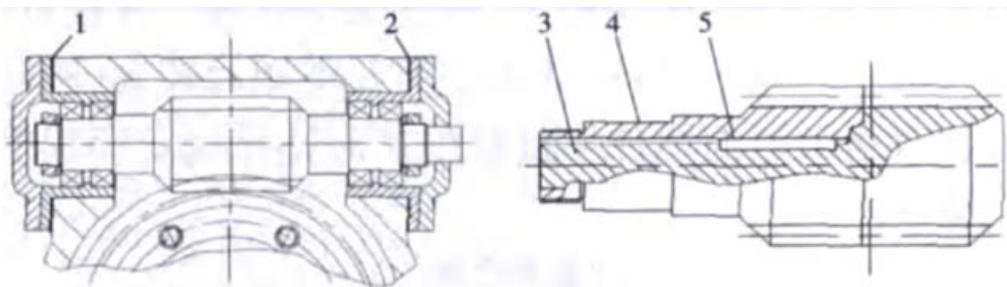
Fig 2. Two-stage worm gear worm gear anti-backlash diagram

As shown in Fig. 2, 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. 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 work piece processing.

Disadvantages: high cost, low transmission efficiency, cannot 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.

2.2 Split worm structure



1-Worm shaft left collar, 2-Worm shaft right collar, 3-Active side worm, 4-Driven side worm, 5-key

Figure 3. Split worm structure

The structure of the split worm is shown in Figure 3. The active side worm 3 (semi-worm shaft) and the driven side worm 4 are relatively slidable by the key 5. When adjusting the gap, the thickness of the spacers 1 and 2 at both ends of the worm is changed, so that the two worms are relatively moved by the sleeve cups at both ends, and finally the purpose of adjusting the side gap of the worm wheel is achieved [5].

Advantages: The machining tool of the worm wheel adopts the standard tool. When the worm is roughed, it is processed separately and assembled and then ground. Therefore, it is easier to adjust the backlash. Compared with the standard worm gear mechanism, the cost is basically not increased.

The disadvantages are obvious: the integrity of the worm is changed, and the pair of meshing teeth is relatively reduced by about half during the transmission, so the ability to transmit the load is relatively weakened.

2.3 Double lead worm drive structure

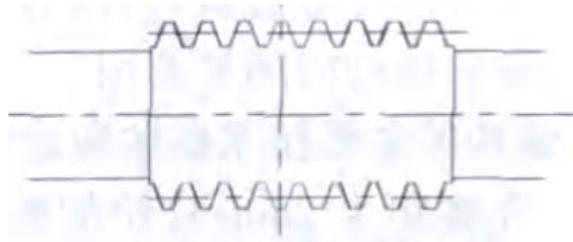


Figure 4. Double lead worm

In the double-lead worm gear pair, the tooth thickness of the worm is gradually thickened or thinned from one end to the other end, and the left and right sides have different lead directions, that is, the left and right sides have different modulus. As shown in Figure 4. The tooth thickness of the worm on the same side of the flank is the same from the other end to the same tooth pitch, so the meshing condition is not broken. Figure 5 is an assembled view of the structure in which the worm can be moved axially by varying the thickness of the shims to adjust the meshing backlash of the worm gear pair [5].

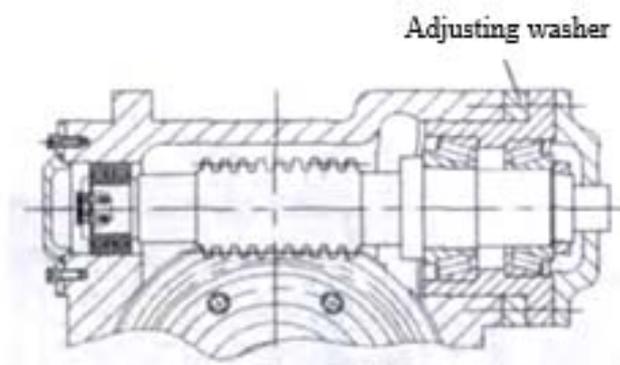


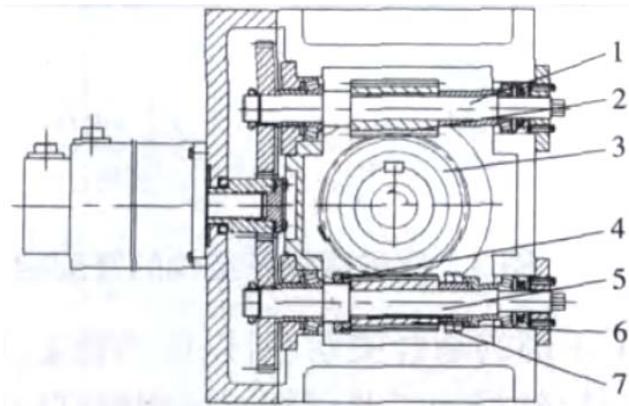
Figure 5. Double lead worm structure assembly drawing

Advantages: The meshing backlash can be adjusted very accurately. Since the double-lead worm maintains the correct meshing relationship, the transmission is stable and the accuracy is maintained.

Disadvantages: The worm machining should design and manufacture special tools according to the parameters of the double-lead worm, which has poor versatility and high manufacturing cost.

2.4 Double worm drive structure

The adjustment of the backlash of the double worm worm gear pair is caused by one worm in the double worm moving in the axial direction, pushing the worm wheel to rotate slightly, so that the two sides of the worm wheel are respectively in contact with the different tooth faces of the two worms, thereby ensuring that the main shaft has both positive and negative reversals. With a small backlash, this structure achieves the purpose of adjusting the gap by adjusting the position of the worm on the shaft.



1-Upper worm shaft, 2-Upper worm, 3-turbine, 4-Left adjustment nut, 5-Lower worm shaft, 6-Lower worm, 7-Right adjustment nut

Figure 6. Double worm drive structure

Figure 6 is a schematic diagram of a double worm drive. The adjustment method of the meshing clearance of the worm and the worm wheel is that the left adjusting nut 4 and the lower worm shaft 6 adjusting nut cooperate with each other to adjust the position of the lower worm 6 on the worm shaft 5, thereby ensuring the normal meshing of the upper worm 2.

Advantages: The machining tool of the worm wheel adopts standard tools, which is convenient to adjust, stable in transmission and good in precision [6].

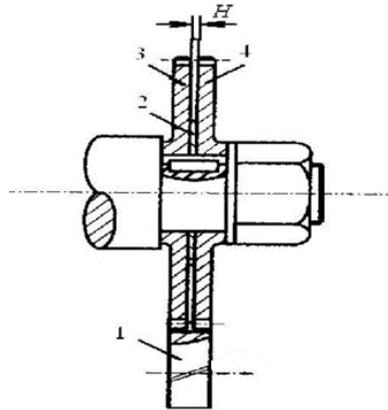
Disadvantages: Because of the addition of a worm, the structural space requirements are relatively high, and the cost is relatively increased, but the single-piece small batch production is still more economical than the double-lead worm.

3. HELICAL GEAR TRANSMISSION STRUCTURE TURNTABLE

Compared with worm gear transmission, the two-stage helical gear has the advantages of high transmission efficiency, low heat generation, low wear, low cost and large transmission torque. However, there are also common helical gear transmissions that are driven compared to the worm gear mechanism. The problem of poor accuracy and stability, so in the modern turntable research, the gear transmission elimination gap structure has received much attention.

3.1 Single helical gear washer adjustment structure

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 7. Helical washer adjustment mechanism

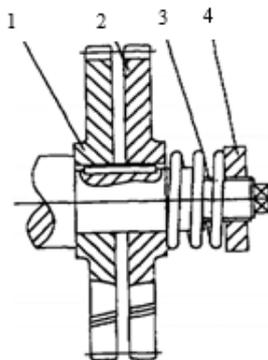
As shown in Figure 7: $B_3+B_4+H=B_1$ (where B is the tooth width). The gears 3, 4 are mounted together and machined with a guide flat key and can be meshed with the gear 1 at the same time. At the same time, the adjusting pad 2 of thickness H is inserted between 3 and 4, so that the spiral lines of 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 [7]:

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

Advantages: simple structure and low manufacturing cost.

Disadvantages: The adjustment is complicated (repetitive grinding is required to ensure $H = \Delta \cos \alpha$), automatic backlash cannot be realized, and the transmission torque is small[8].

3.2 Single helical gear axial compression spring adjustment structure



1-Sheet gear 1, 2-Sheet gear 2, 3-Compression spring, 4-Adjustment nut
 Figure 8. Single helical gear axial compression spring adjustment structure

As shown in Fig. 8, the single helical gear axial compression spring adjustment structure is the same as the above-mentioned single helical gear gasket adjustment structure, except that the

gasket adjustment is replaced by an axial compression spring automatic adjustment, so that two pieces mesh with the wide gear. The thin gears are in close contact with each other, and then the spirals are staggered from each other to finally eliminate the positive and negative reversal gaps [9].

Advantages: automatic compensation of gear backlash

Disadvantages: large axial size and compact structure.

4. TO SUM UP

In this paper, the common side clearance mechanism of several machine tool turrets is summarized. For the variable tooth thickness axial adjustment structure, the bevel gear double sprocket tooth adjustment structure and other complex and not widely used machine tool lag gear anti-backlash mechanism is not introduced. It provides a certain reference for the selection and design of the anti-backlash structure of the machine tool table.

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