Calculation of Turntable Transmission Error of Intelligent Five-Axis Machining Machine

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Abstract

In order to study the influence of the accuracy of the feed motion of the five-axis CNC machine tool turntable on the machining accuracy of the machine tool and the predictive compensation of the transmission error of the double gear backlash mechanism, this paper firstly adopts the dual gear anti-backlash mechanism of the five-axis machine tool turntable. Eliminate the gap in the reversing drive and improve the machining accuracy of the machine tool. Secondly, it analyzes the main influencing factors affecting the transmission error of the double gear anti-backlash mechanism. Finally, according to the randomness of the gear errors, Monte Carlo method is used. The transmission error of the double-gear anti-backlash mechanism is calculated and analyzed, and the comprehensive transmission error of the dual-gear anti-backlash mechanism of the five-axis turret is obtained. The research results show that the feed motion of the five-axis machine tool turntable determines the machining accuracy of the machine tool. The Monte Carlo method can accurately calculate the transmission error of the double-gear anti-backlash mechanism of the five-axis machine tool turntable, providing theoretical and data support for subsequent error compensation. .

Keywords

Five-axis machine; tool turntable; double gear backlash; error analysis.

1. Foreword

Five-axis CNC machine tools are becoming more and more frequent in the processing of complex curved surfaces and high-precision parts. The turntable is an important transmission feed system for five-axis machine tools. It is being studied and paid attention to [1], and its transmission accuracy directly affects the precision of machined parts. . At present, most of the five-axis CNC machine tools in the market use a worm gear mechanism for the feed table, but it has low transmission efficiency and large reverse drive clearance [2]; The reverse drive clearance is eliminated, and the center-to-center accuracy of the two gears is required to be low during installation [3]. Therefore, the use of a dual gear anti-backlash mechanism as a turntable for a five-axis machine tool is an irresistible trend. The relevant parameters of the five-axis machine tool are shown in Table 1:

stroke	X-axis stroke 1250mm	X-axis stroke 1250mm (including tool change stroke 200mm)
	Y-axis stroke	Y-axis stroke 400mm
	Z2 axis stroke	Z2 axis stroke 450mm
	A-axis	A-axis 360°
	B axis	B axis ±40°

	Distance from the end face of the spindle to the center of rotation of the turret (Z axis)	0-450mm
	Distance from spindle centerline to turntable centerline (Y-axis)	±200mm
Blade processing range	Maximum blade processing length	400mm
	Maximum blade machining diameter	300mm
Turntable	Turntable motor power 8Kw	Turntable motor power 8Kw
	Number of turntables 1	Number of turntables 1
	Top	Top The right side is the top, you can choose the fixed top or the replaceable top according to your needs.
Spindle	Spindle rotation number	200-15000r/min
	Spindle taper	HSK 63 A
	Spindle maximum power	35KW
	Spindle torque	100/130 Nm
Fast moving speed	X, Y / Z axis	40m / min
	A axis	80r/min
	B axis	30r/min
accuracy	Linear axis positioning accuracy (X, Y, Z)	0.008mm
	Rotary axis positioning accuracy (A / B)	15″ / 18″
	Linear axis repeat positioning accuracy (X, Y, Z)	0.006mm
	Rotary axis repeat positioning accuracy (A/B)	12″/15″
machine tool	Machine weight is about	12,000Kg
	Dimensions	5100×3000×2700

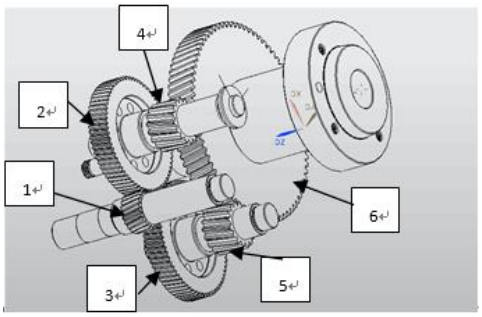

FIG.1 Three-dimensional diagram of double helical gear anti-backlash mechanism

Double gear anti-backlash mechanism：

In order to realize high-precision machining of aero-engine blades on a five-axis CNC machining machine, a double helical gear anti-backlash transmission mechanism is adopted for the turntable. The gear train of the turntable will inevitably produce certain transmission errors during operation, which will have a great impact on the machining of high-precision parts. The double-skew gear backlash transmission system can realize the forward and reverse rotation of the turntable, and the

reversing drive has no gap. Eliminate the positive and negative gaps and improve the machining accuracy. The three-dimensional diagram is shown in Figure 1.

Influencing factors of transmission error of double gear anti-backlash mechanism：

The transmission error of the double gear anti-backlash mechanism can be regarded as the deviation of the actual rotational position of the output gear 6 from the ideal rotational position. A large number of studies [4-5] show that the gear transmission error is composed of inherent position error and device error.

The inherent position error of the gear can be given by:

$$\Delta E^{'} = \frac{1}{2}\left(\Delta F_i^{'} - \Delta f_i^{'}\right)\sin\theta + \frac{1}{2}\Delta f_i^{'}\sin\left(z\theta\right) \tag{1}$$

In the formula (1): It represents the inherent position error of the gear, and represents the tangential integrated error, which represents the single-tooth tangential integrated error, and represents the gear phase angle, which represents the number of gear teeth.

And respectively are the large and small period parts of the inherent position error of the gear, wherein the random variable and the Rayleigh distribution obey the Rayleigh distribution, and the phase angle of the random variable obeys the uniform distribution in the interval of [0, 2π] [6].

During the actual movement of the dual gear anti-backlash mechanism, the rotational center position of the gear 6 is very important. The device error is the deviation of the actual center of rotation of the gear 6 from the theoretical center of rotation[7], which is equivalent to the geometric eccentricity of the gear 6. The device error consists of the gap between the gear hole and the shaft, the radial runout of the journal at the gear mounting, and the radial runout of the bearing. The calculation formula of the transmission error caused by it is as follows:

$$\Delta E^{''} = \sum_{i=1}^{3}\Delta e_i \sin\theta_i \tag{2}$$

In equation (2): indicates the transmission error caused by the device error; indicates that the runout of each gear obeys the normal distribution; the phase angle indicating the runout of each gear is uniformly distributed over the interval [0, 2π] Random variable.

2. Mathematical model

2.1 Single gear error

In the calculation of gear transmission error, the transmission error of a single gear is composed of the inherent position error of the gear and the device error. The calculation formula of the transmission error of a single gear is as follows:

$$\Delta E = \Delta E^{'} + \Delta E^{''} = \frac{1}{2}(\Delta F^{'} - \Delta f^{'})\sin\theta + \frac{1}{2}\Delta f^{'}\sin(z\theta) + \sum_{i=1}^{3}\Delta e_i \sin\theta_i \tag{3}$$

2.2 Transmission error of a pair of gear pairs

The transmission error of a pair of gear pairs is a combination of the transmission errors of the two gears that mesh with each other. The calculation formula is as follows:

$$\Delta\theta_f = \frac{\Delta E_1 + \Delta E_2}{\mathrm{R2}} \tag{4}$$

In the formula (4): a transmission error indicating a pair of gear pairs; and a transmission error indicating a driving gear and a driven gear, respectively; and R2 indicating an indexing circle radius of the driven wheel gear.

2.3 Gear transmission system transmission error

A gear transmission system is generally composed of a plurality of pairs of gear pairs. The transmission error of the system is that the transmission error of each pair of gear pairs is added to

the reading gear. As shown in Figure 1, for a gear transmission system, if the 4-axis is the reading gear shaft, the calculation formula of the system transmission error is as follows:

$$\Delta\theta = \frac{\Delta\theta_{f1}}{i_2} + \frac{\Delta\theta_{f2}}{i_3} + \Delta\theta_{f3} \tag{5}$$

In the formula (5): the angle value of the system transmission error; , , represents the transmission error of the gear pair 1, 2, 3, represents the transmission ratio of the 2 to 3 axes; represents the transmission ratio of the 3 to 4 axes.

In the actual working environment, if the nth axis is the reading gear shaft, the calculation formula of the gear transmission error of the system is as follows:

$$\Delta\theta = \frac{\Delta\theta_{f_1}}{i_2} + \frac{\Delta\theta_{f_2}}{i_3} + \cdots + \frac{\Delta\theta_{f_{n-1}}}{i_n} + \Delta\theta_{f_n} \tag{6}$$

In the formula (6): represents the transmission error of the nth pair of gear pairs, and represents the transmission ratio of the nth axis to the n+1 axis of the nth pair of gear pairs.

3. Calculation of transmission error of double gear anti-backlash mechanism

The power of the turntable in this analysis is 8Kw, the speed is 60r/min, and the turntable adopts a large torque servo motor, which ensures the high torque and high responsiveness through the two-stage gear reduction transmission. The gear reduction mechanism adopts a double gear anti-backlash mechanism and a high-precision angle encoder to ensure high rotation precision and repeat positioning accuracy of the turntable.

The tolerance parameters of the gear are shown in Table 1:

Table 1 Gear main parameters

project	Gear 1	Gear 2, 3	Gear 4, 5	Gear 6
Number of teeth	28	67	16	77
$\boldsymbol{F_i'}$/μm	8	44.6	30.6	46.2
$\boldsymbol{f_i'}$/μm	0	9.6	9.6	11.2
$\boldsymbol{e_1}$/μm	0	27	0	9
$\boldsymbol{e_2}$/μm	8	12	0	10
$\boldsymbol{e_3}$/μm	8	8	6	13

The distribution parameters of the gear are shown in Table 2:

Table 2 Gear distribution parameter

project	Gear 1	Gear 2, 3	Gear 4, 5	Gear 6
η1	2.94	5.15	3.09	5.15
η2	1.18	1.41	1.41	1.65
μ1	0	13.5	0	4.5
	0	4.5	0	1.5
σ1	0	6	0	5
	0	2	0	1.67
μ2				
σ2	4	4,3	4,3	6.5
μ3	1.33	1.33	1.33	2.17
σ3		1	1	

Combined with the previous mathematical model and Monte Carlo method, the calculation formula of the transmission error applied to the double-gear backlash mechanism of the five-axis machine tool turntable is as follows:

$$\Delta\theta = \frac{\Delta E_1 + \Delta E_2}{r_2} * \frac{Z3}{Z4} + \frac{\Delta E_3 + \Delta E_4}{r_4} \tag{7}$$

Based on the sampling function and distribution of the random variable, the Monte Carlo method is used to perform 10,000 random samplings on the double-gear anti-backlash mechanism[9]. The transmission error distribution of the dual-gear anti-backlash mechanism is shown in Fig. 2, which is obtained under a certain confidence. The maximum transmission error of the double gear anti-backlash mechanism is ±0.023°:

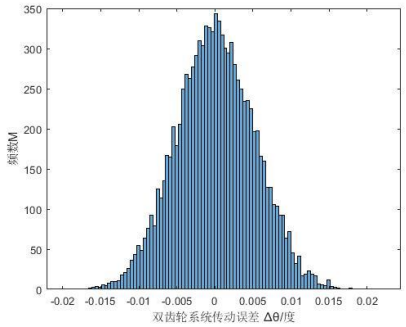

FIG.2 Transmission error histogram

After normalization [10], the Gaussian fitting effect diagram between the histogram of the transmission error and the normal distribution shows that the transmission error of the gear system is normally distributed, as shown in Figure 3:

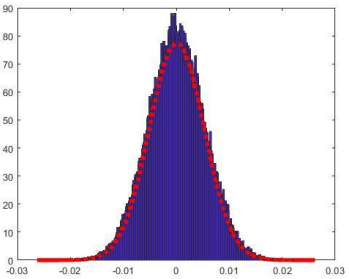

FIG.3 Gaussian fitting

4. Conclusion

Conclusion 1: The double-gear anti-backlash mechanism of the five-axis machine tool turret can realize the forward and reverse rotation of the turret, the reversing drive has no gap, eliminate the positive and negative reversal gap, and improve the machining accuracy.

Conclusion 2: The influence factors of the transmission error of the dual gear anti-backlash mechanism of the new five-axis CNC machine tool turntable satisfy the large number theorem and the central limit theorem. According to this feature, the Monte Carlo method is used to calculate the transmission error of the double gear anti-backlash mechanism. The maximum value of the transmission error is ±0.023°, and the Gaussian fitting obtains the transmission error to satisfy the normal distribution, which provides a certain theory and reference for the future real-time error compensation of the dual gear anti-backlash mechanism.

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