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APPLICATION OF MULTIAXIAL CNC TECHNOLOGY IN PRECISION MOLD MANUFACTURING

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Abstract

Advanced multi-axis CNC machine tools are the key to the manufacturing industry. The development of the CNC machining technology changes with each passing day, the realisation of the CNC system sample precision insertion function makes the precision mold processing quality and precision has been greatly improved. However, in the actual processing, due to the limitations of various factors, the CNC system still faces many urgent problems in the process of interpolation processing, such as complex calculation and large speed fluctuations. These problems are mainly reflected in two aspects: real-time calculation of interpolation parameters and interpolation speed planning. Therefore, this paper mainly studies the optimisation of the insertion accuracy and the insertion speed in the NC system.

Key Words

Control instruction, precision interpolation, high precision compensation, dynamic precision compensation

1. Introduction

In the manufacturing industry, the development of multi-axis CNC technology has made great achievements so far. As a high-tech, it plays a very important role in the precision die manufacturing industry, and the development level of the manufacturing industry has become one of the important indicators to measure a country's comprehensive strength level. With the rapid development of modern CNC technology and precision die manufacturing, European and American countries have put forward more stringent requirements on the quality, precision, and production efficiency of precision die manufacturing, so in this case, multi-axis CNC machining technology is not only facing great opportunities but also very severe challenges. High-performance manufacturing plays an important role in modern industry [1]. The machining accuracy in the process of CNC directly determines the core competitiveness of China's machinery production and processing industry. Therefore, the related enterprises in the manufacturing industry must make more in-depth analysis and research on multi-axis CNC technology to meet these challenges and opportunities, in order to gradually improve the level of the whole manufacturing industry [2].

2. Research Status of CNC System Error Compensation

In the manufacturing industry, error avoidance and error compensation are two methods to improve machining accuracy from different angles. From the composition of the CNC machine tools, it is generally composed of the bed body, column, spindle, and guide rail, due to mechanical manufacturing, assembly and actual processing, and other reasons, each part of the CNC machine tools will produce a certain error [3]. The error causes can be divided into programming error, geometric error, thermal error, control error, stiffness error, load error, and other errors. Error, as an inevitable phenomenon in the processing process, cannot be completely eliminated through the machine tool structure design, and the error avoids the hardware transformation, to a certain extent, half the result with twice the effort, even if it can be realized, it also needs to cost a huge economic cost [4].

The complexity and nonlinearity of the processing state determine that the advanced control strategy cannot completely inhibit the generation of error, but because the error compensation without transforming the hardware equipment, it can greatly improve the processing performance, so it is favoured by people, and gradually developed into one of the main methods to improve the machining accuracy of CNC machine tools [5].

Tracking error is the focus of attention in the processing process, the purpose of compensation is to reduce the tracking error, as the cause can be ignored, and focus on the final results, based on the final error of direct error compensation is the most direct way. The

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realisation of error compensation should not only meet the compensation accuracy but also meet the convenience and economy of practical application. The implementation of error compensation can be obtained by modifying the G code [6] and modifying the internal parameters of the NC system.

2.1 Parameter Fine Analysis of Spatial Free Curve Supplement Method

A real-time high-precision interpolation algorithm for spatial free curves based on discrete data points. Based on the geometric information such as curves, surfaces, tool contact trajectory lines, and process information such as tools and machining allowances read in the interpolator, the tool location trajectory lines are reconstructed in real-time in the form of parameter cubic polynomial curves. The reconstruction effect is compared with existing small linear segment continuous interpolation and PMAC card spline interpolation methods to provide real-time interpolation algorithms. Then, a spatial free curve tool location trajectory line during complex surface machining is taken as an example, Analyze and propose the characteristics and performance of interpolation algorithms, set accuracy and speed, real-time performance, interpolation accuracy, feed rate fluctuations, etc. and construct adjustable real-time interpolation parameter modules for spatial free curves to meet the needs of secondary development of CNC systems [7].

The accuracy of free curve interpolation algorithm is determined by the bow height error, *i.e.*, the actual contour error is calculated by approximating the local geometry of the curve as a circular arc. This is a reasonable approximate method for numerical calculation when the arc length of the curve section is extremely small. Existing free curve interpolators use chord feed instead of arc feed because absolute arc machining is difficult. Compare the precision of the free curve interpolator with that of the chord length interpolator. Chord length interpolator can achieve the precision level of free curve interpolator. However, to process complex geometric parts more accurately with chord length interpolators, smaller chord length tolerances need to be developed in CAM software, which will result in more and shorter chord lengths, which in turn will lengthen the processing program and increase the code file. Although modern CNC system can process a large number of processing code programs quickly and effectively, and free curve interpolator cannot provide higher accuracy than chord length interpolator, the code for high-precision machining is much simpler. Under the same accuracy requirement, a spline curve program section can replace at least 5–10 linear interpolation instructions [8]. In order to achieve the same interpolation accuracy, the amount of processing code required for curve interpolation is much smaller and the fluctuation of feed speed is small, which has unique advantages and great application prospects [9].

Free curve interpolation technology arises with the high speed and high precision processing requirements of complex surfaces. Because of the high operational complexity, the application of real-time curve interpolation is limited. The premise of applying the free curve interpolation algorithm is that the knife locus trajectory can be expressed as the mathematical model form of the free curve. The general curve contour is difficult to express as the curve form before the same isometric time, which also limits the application of the free curve interpolation algorithm. The key technology of real-time free curve interpolation also involves the real-time performance of the interpolation algorithm, the obtaining of [10] parameter increments that meet the requirements of processing accuracy and the kinematic and kinetic characteristics of the processing equipment.

3. High-precision Cutting Auxiliary Function of CNC Machine Tools

3.1 High-precision Control Instruction G61.1 Control ON

Here, take the MITSUBISHI-MELDAS65M system as an example: the high-precision control function can effectively eliminate the delay of the control system when the control, when the servo system operation process delay, especially in the use of high-speed cutting processing, this function can improve the cutting accuracy, and shorten the processing time. The high-precision function instruction G61.1 is a combination of the following element functions (Fig. 1).

3.2 Increase and Deceleration before Program Insertion

By performing acceleration and deceleration before interpolation, it can smoothly eliminate the machining shape error and obtain a high-precision trajectory. In the arc instruction, the radius can greatly reduce the error. Moreover, performing constant slope acceleration and deceleration can shorten the positioning time of small distances in the G00 instruction [11].

(Note 3.1) Independent of the high-precision control designation, you can choose whether to perform the fast feed (G00) instruction through the parameter setting.

3.3 Optimum Angle Deceleration

Through the automatic judgement of the instruction vector angle deceleration, high-edge and high-precision processing trajectory, the deceleration speed at the angle is shown as follows (Fig. 2). In addition, though the S-type filter can make the track speed change more gently, choke the vibration of the machinery, and improve the accuracy of the cutting processing surface. In terms, the machining [12] with high-edge trajectory can be realised by reducing the high-edge vector.

3.4 Feedforward Control

With the unique feedforward control of the CNC system, the very small and stable servo error can be realised (Fig. 3).

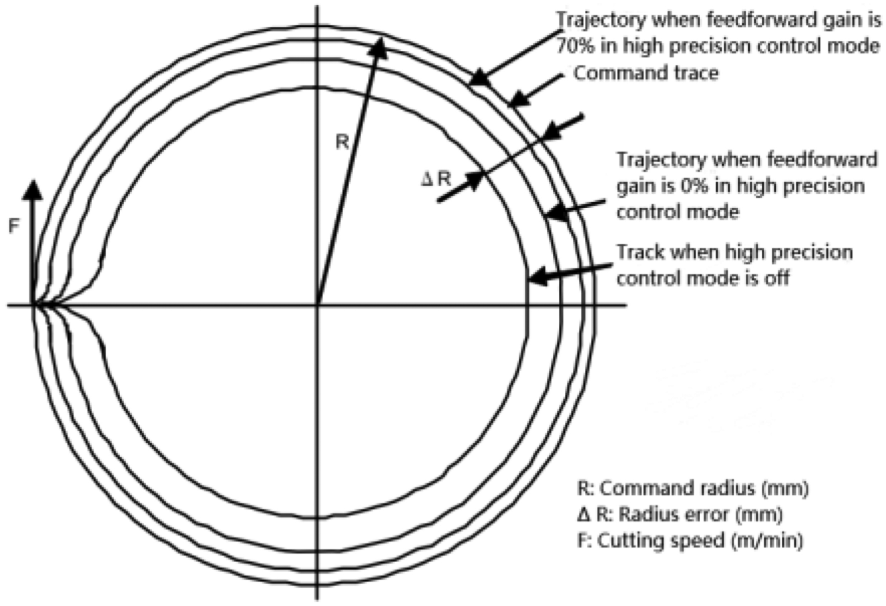

Figure 1. The effect of G 0 2 and G 0 3 interpolation in the circular arc.

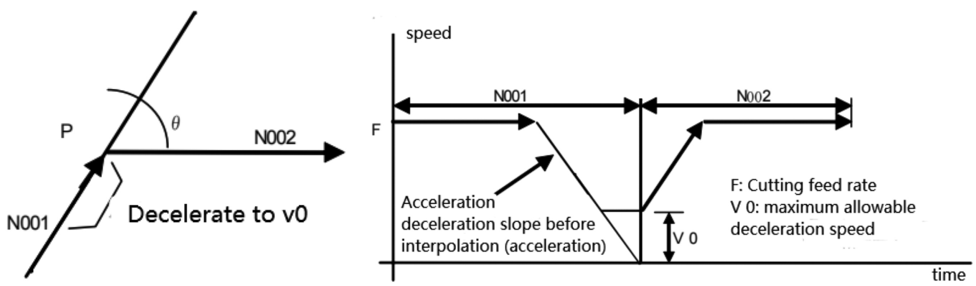

Figure 2. Optimal angular deceleration high-precision control mode.

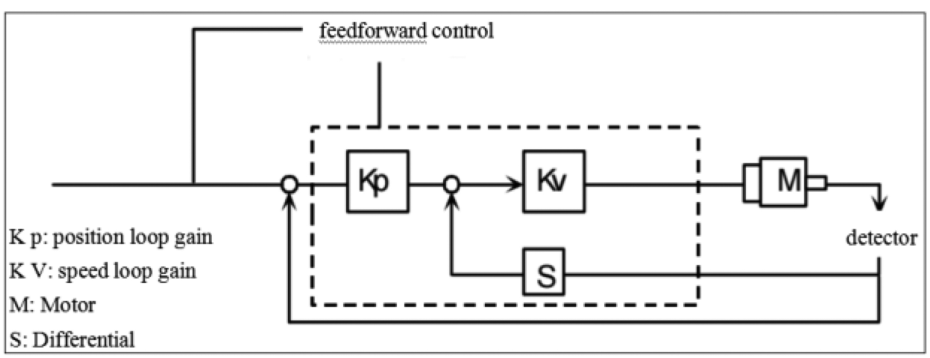

Figure 3. Servo control.

3.5 Track Vector with High-precision Interpolation

When the small line segment trajectory interpolation instruction is given, and the connection angle between the program segment and the program segment is very small and smooth (without the optimal angle deceleration), the automatic fine interpolation can be performed more smoothly through the vector high-precision interpolation function (Fig. 4) [13].

3.6 Arc Inlet/outlet Trajectory Speed Control

If the trajectory passes through the joint of straight line → arc or arc → straight line, the acceleration change and mechanical vibration may occur. Before entering the arc and when the arc appears, slow down to the speed set in the parameters to reduce the vibration of the machine. However, when combined with angular deceleration, the party with the lower deceleration speed is effective [14].

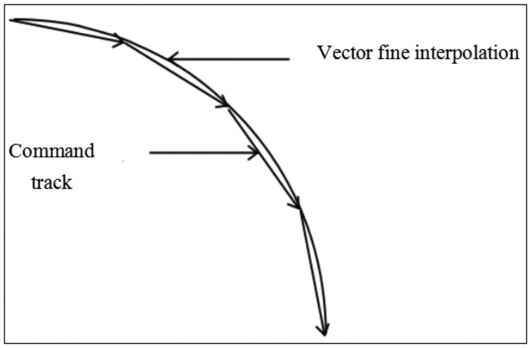

Figure 4. High-precision vector interpolation.

3.7 Arc Radius Error Compensation

Compensation for inward movement due to servo delay during arc cutting.

3.8 Type S-filter Control

More smoother interpolation of the small line segments assigned to each axis through vector high fine interpolation. Effectively changes the variation due to feed-forward control and reduces the impact on machinery.

Examples of procedures:

The G64 is disarmed under G6.1 and becomes a high-precision control mode.

N01G28X0Y0;

N02G90G00G54X0Y0;

N03G91G01G61.1F2000; the high-precision control mode is turned on

N04X200;

N05X200.Y-200;

N06X-200.Y-200;

N07X-200;

N08X-200;

N09Y-200;

N10X200.Y200;

N11G64; the high-precision control mode is turned off

N12M30;

3.9 Spiral Insertion

On the three axes that intersect at a right angle, while the arc insertion is conducted on any two axis, the linear insertion is synchronised with the arc on the other one axis, so as to realise the processing of large diameter thread and three-dimensional cam.

G17 G02(G03) Xx1 Yy1 Zz1 Ii1 Jj1 Pp1 Ff1;

G17 : Arc plane

G02, G03: arc rotation direction

Xx1, Yy1: arc end coordinates

Zz1 : the end coordinate of the linear axis

Ii1, Jj1: circular arc center coordinates

Pp1 : Number of spirals

Ff1 : Feed speed

1. Specify the arc plane by G17, G18, G19.
2. Specify the direction of the arc rotation *via* either G02 or G03.
3. Arc end coordinates, and line axis end coordinates can be specified absolute/incrementally, but the arc center coordinates must be specified incrementally.
4. The line interpolation axis is another 1 axis not included in the plane selection.
5. Specify the feed speed as the direction of the composition on each axis.

In addition, the pitch/1 is calculated by the following formula.

$$/1 = z1/((2\pi, p1 + \theta)/2\pi)$$
$$\theta = \theta e - \theta s = \arctan(ye/xe) - \arctan(ys/xs)$$

Here, xs and ys are the starting coordinates ($0 \leqq \theta < 2\pi$)

The xe and ye are the end-point coordinates

The combination of axes that can be instructed simultaneously depends on the specification. Shaaxes can be combined. The feed speed is usually controlled to the speed [15] along the circumference.

Example (Fig. 5):

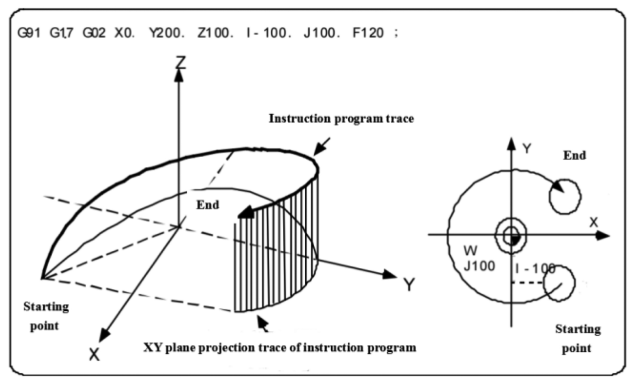

Figure 5. Spiral insertion.

3.10 Vortex/Conic Insertion

Vortex smooth interpolation of the starting and end arc not on the same circumference.

G17 G02.1(G03.1) Xx1 Yy1 Ii1 Jj1 Pp1 Ff1;

G17: Rotation plane

G02.1, G03.1: circular arc rotation direction

Xx1, Yy1: endpoint coordinates

Ii1, Jj1: Arc center value

Pp1: Number of spirals

Ff1: Feed speed

The arc insertion action is performed at the speed of f1 by the above instruction. The path is oriented toward the endpoint, and the vortex arc track [16] is centered on the specified position (the X-axis direction distance i1 and the Y-axis direction distance j1).

Specify the arc plane by G17, G18, G19.

G17...... XY plane

G18...... ZX plane

G19...... YZ plane

Specify the direction of the arc rotation *via* either G2.1 or G3.1.

G2.1..... Clockwise (CW)
G3.1..... Counterclockwise (CCW)

Specifies the number of pitch (rotations) by p1
If p1=0 is less than 1 turn, the address setting can be omitted. The p1=1 is more than 1 turn, less than 2.
Example (Fig. 6):
G91G17G01X60.F500;
Y140. ;
G2.1 X60. Y0 I100. P1 F300 ;
G01 X-120 ;
G90
G17 G01 X60. F500;
Y140.;
G2.1 X120. Y140. I100. P1F300 ;
G01 X0;

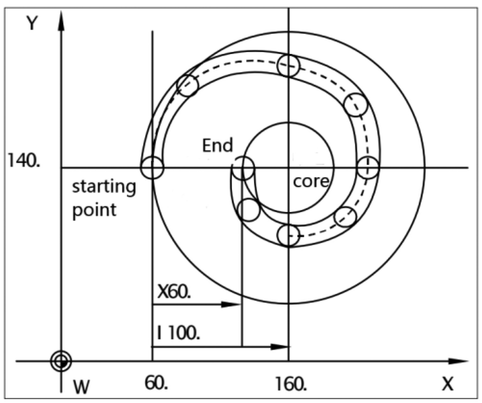

Figure 6. Vortex/conic insertion.

1. The combination of axes that can be instructed simultaneously depends on the specification. Any combination within the specifications.
2. The feed speed shall keep the wiring speed constant.

3.11 Cylinder Interpolation

The function of contour control is to spread the shape of the side of a cylinder (the shape in the cylindrical coordinate system) into a plane, issue program instructions using the shape obtained after expansion as planar coordinates, and convert it into the movement of the linear axis and rotation axis of the original cylindrical coordinate in CNC during machining. Because the shape of the cylindrical side can be programmed, it is an effective function for processing cylindrical cams, *etc.* (Fig. 7) [17].

1) *Cylinder interpolation mode starts*
(G07.1 Rotating Shaft Name Cylinder Radius Value;)
Cylindrical interpolation is performed between the rotating shaft specified in the program section of G07.1 and any other straight axis.
   a. In the cylindrical interpolation mode, instructions for straight or arc interpolation are available. But before the program section of G07.1, proceed with the G19 (plane command) instruction.
   b. Both absolute and incremental coordinate commands are acceptable.
   c. Additional tool diameter compensation can be applied to program instructions.
   Carry out cylindrical interpolation for path compensated by tool diameter.
   a. Please specify the wire speed after cylinder expansion as the feed speed according to F. F is in mm/min or inch/min.

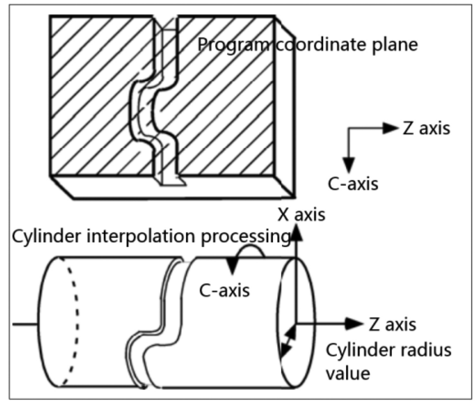

Figure 7. Cylinder insertion.

2) *Cancellation of cylinder interpolation mode*
(G07.1 Rotating shaft name 0;)
When the rotating shaft is named "C," enter the cylinder interpolation cancellation mode by the following instructions.
G07.1 C0;

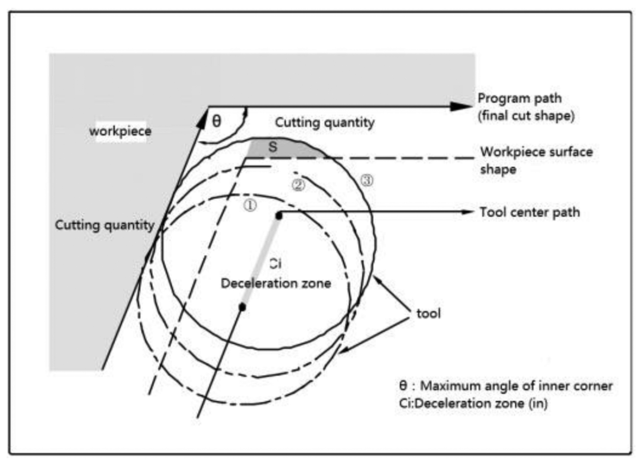

Figure 8. Cutting action.

3.12 Support for Precision Machining

When cutting the angle part, in order to prevent the machining surface from being skewed due to the increase of the cutting load, a multiplier is automatically added to the cutting feed speed to ensure that the cutting amount will not increase in a certain period of time at the angle [18].

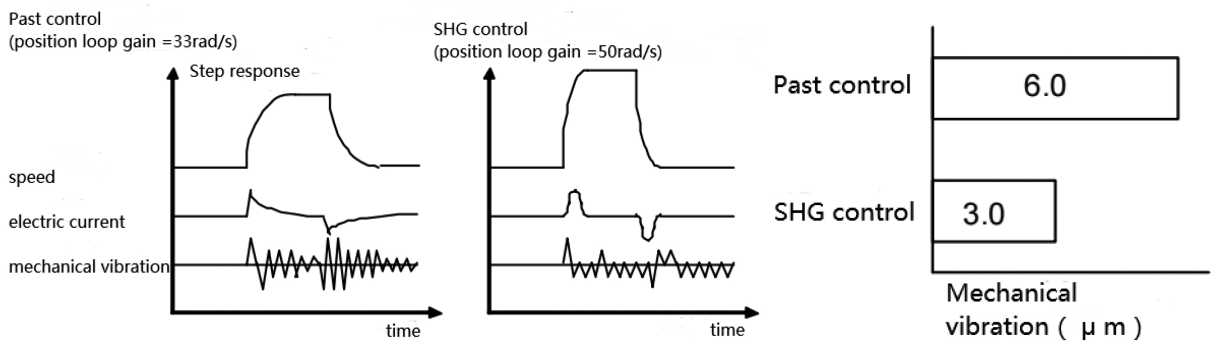

Figure 9. SHG control and mechanical vibration amount comparison.

Automatic angle multiplier is only effective in tool diameter compensation. Through the instruction of G62, the automatic angle multiplier ON, the following G instruction will release the automatic angle multiplier mode.

G40....................... Tool path compensation is cancelled
G61....................... Accurate stop check mode
G63....................... Tapping mode
G64....................... Cutting pattern
G61.1..................... High precision control mode

Cutting action:

1. without adding the automatic angle multiplier (Fig. 8), when the tool moves in the order of ①→②→③, because ③ has more cutting quantity than ② the area of the diagonal S, the tool load increases.
2. When the automatic angle multiplier is attached, in Fig. 8, when the angle θ of the inner angle is less than the angle set in the parameter, within the deceleration area Ci, the multiplier set in the parameter is automatically attached.

3.13 Mechanical Static Accuracy Compensation

3.13.1 Backward Gap Compensation

The function of compensating for the error (back gap) in the direction reversal of the mechanical system. In backgap compensation, it can be set in cutting feed mode and fast feed mode. The backgap compensation amount of each axis can be set independently. The setting is performed by the number of pulses with a set unit scale of 1/2 of the minimum set unit. Furthermore, the output depends on the output unit system. Output unit system refers to the mechanical system (unit system of ball screw). The backgap compensation amount [19]–[20] can be set for each axis in the range of 0 to ± 9,990 (pulse).

3.14 Memory-type Relative Position Error Compensation

By compensating the relative error (manufacturing error, aging, *etc.*), the mechanical accuracy is improved. Set the compensation reference axis and the compensation execution axis through the parameters. The compensation points can be divided at any equal intervals.

3.14.1 to 9999999 (output)
3.14.2. Compensation points... 1024
3.14.3. Compensation amount... -128 to 127 (testing unit)
3.14.5 (including memory pitch error compensation)

(3.14.1) Set the compensation position for the compensation axis with 0 point as the reference point. Therefore, after the control device power supply is turned on, and after the servo ON, the axis without the reference point back to zero is not compensated.
(3.14.2) When the compensation base axis is the rotation axis, please select the equal partition interval and make an equal segmentation for one rotation.
(3.14.3) Through this compensation, all the coordinate systems of the execution axis can compensate for the offset, and the stroke checkpoint and mechanical coordinate system are also offset.
Note: (3.14.1) The compensation point of 1024 points is the total value of the memory pitch error compensation.
Note: (3.14.2) 0∼99 times of the compensation.

3.15 Dynamic Trajectory Accuracy Compensation

3.15.1 Smooth High Gain (SHG) Control

When using the servo system (MDS- □ -V □/SVJ2), the high-response, safer position control mode. Compared with previous control methods, SHG control can achieve about 3 times the position loop gain equivalent to previous control methods. The characteristics of the SHG control are as follows (Fig. 9).

1. The trajectory acceleration and deceleration becomes smooth and can choke the mechanical vibration generated by (about 1/2) during the acceleration and deceleration. (That is, the trajectory acceleration and deceleration time constant can be shortened.)
2. Shape error (Fig. 10) is about 1/9 of the previous control time.
3. The positioning time (Fig. 11) is about 1/3 of the previous control time.

3.16 Double Feedback

According to the frequency, the load (gain) of the position feedback of the motor end detector and the position feedback of the mechanical end detector and the frequency

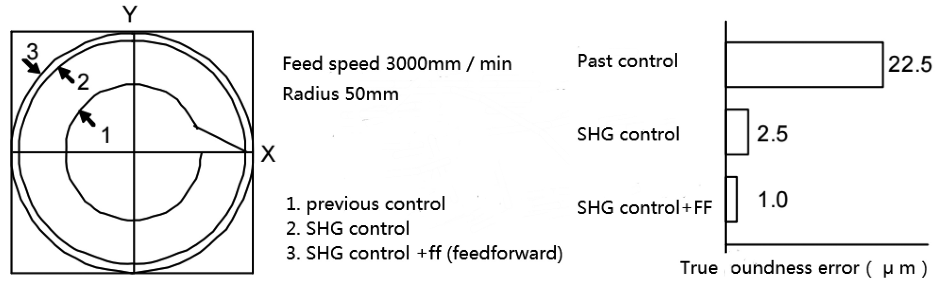

Figure 10. Comparison of shape error accuracy.

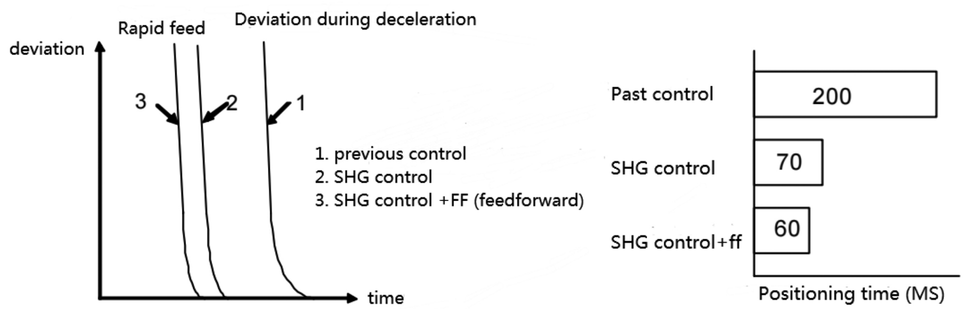

Figure 11. Comparison of positioning time and dosage.

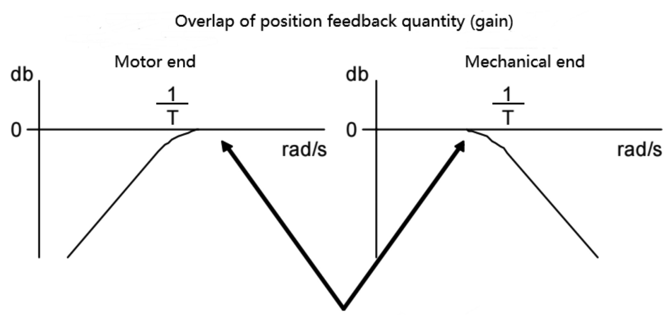

Figure 12. The time constant T is adjusted by the parameters.

show below (Fig. 12), which can be transferred through semi-closed-loop control and positioned through closed-loop control. The time constant [21], [22] of the primary delay filter in the dual feedback control is set in the parameters.

4. The Importance of Maintaining the Thermal Stability of the Machine Tool

When the cutting temperature of the machine tool drops from 25°C to 20°C size change, at 25°C, the workpiece size is 6 μm larger, when the cutting temperature drops to 20°C, the same size is only 0.12 μm larger, this is a process to maintain thermal stability, even if the working temperature drops rapidly, it still needs a period of time to maintain the machining accuracy. A larger material takes longer to recover a stable [23], [24] with precision when the temperature changes.

According to the above analysis of temperature, the manufacturing premise of precision mold is to maintain thermal stability, which is a necessary condition for precision machining. Is it be whether the ambient temperature should be controlled at 20°C or 23°C? In fact, the most important thing is to be able to control a stable target value, which is the key. In theory, the general requirement is 20°C, and the actual workshop usually takes 22°C–23°C, as long as the strict control of temperature fluctuations can be [25].

Epilogue

To sum up, the high-precision interpolation of curved curve surface is one of the key technologies to realise the precision machining of curved surface. A new original error is studied to offset the current error problem, so as to reduce machining error and improve machining accuracy. This error compensation method does not need to transform the hardware, only to ensure that the artificial error and the original error to keep equal size, the opposite direction, can improve the machining accuracy of the CNC system greatly. In the actual compensation, the error compensation mode of the control amount can be modified or input according to the compensation amount inside or outside the control layer. Through the application of high-speed and high-precision compensation instruction, and changing the control quantity parameters in the controller and drive, the CNC machine tools can meet the high speed and high precision requirements of different products and molds. This technology can bring certain reference value to related industries. Further research is needed due to the limitations of author experience, competence, and objective conditions.

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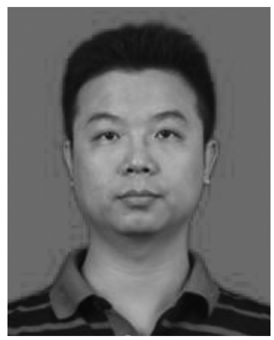

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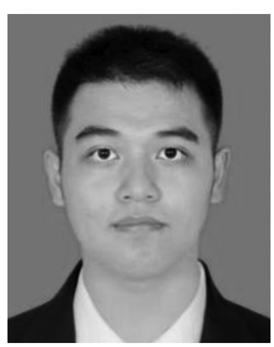

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