

Analysis of Nonlinear Error of Five-axis Machining

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Abstract: For non-linear error because of rotational movement of the rotary axis, have analyzed how non-linear error is generated in the five-axis machining, and have established the non-linear error model of complex surface. Then have proposed a method of compensating for nonlinearity error is interpolate point. By using method of surface interpolation to interpolation point, the tool axis vector will be always kept on sector surface boundary with start and end tool axis vector within the program block, and be maintained the tool axis vector velocity and acceleration continuity. Simulation results show the nonlinearity errors of the fan blade machining are effectively controlled.

Keywords: Five-axis machining, Nonlinearity error, Surface interpolation, Compensation point

1 Introduction

Five-axis CNC machine tools can flexibility control the tool geometry and the workpiece surface achieve a better match. However, because of the introduction of two rotary axes, the five-axis CNC machine tool structure is become more complexity and the postures of the tools are become more difficult to controlling. Due to the rotation axis of movement, five-axis machining of non-linear error is inevitable.

Many scholars have conducted a number of studies on five-axis machining of non-linear error analysis and control. Literature ^[1-3] already analyzed and researched the nonlinear error for five-axis machining, and clarified the principle of nonlinearity error generated, and clarified the adaptive linearization method to control error. Geng Cong et al^[4] proposed a cutter path control algorithm by controlling the movement of the first tool axis vector and the end of tool axis vector on the plane defined, in order to reduce the non-linear error. Fan Liuqun et al [5] studied linear interpolation principle of the angle of rotation axis and what causes nonlinear machining errors, and proposed specific algorithm of tool axis vector interpolation based on tool axis vector plane, thus avoided the non-linear errors. However his method cannot guarantee the continuity of the speed and acceleration of rotating axis.

These methods are all analyzed for piecewise linear the cutting location point. It is the approximate nonlinear error mathematical model based on analysis of single tool path data, and did not consider the information of the complex theory curved surface

in three-dimensional space. Therefore, it is necessary to further study of nonlinear errors modeling and error controlling.

2 Establish Nonlinear Error Mathematical Model

In the interpolation program block, machine axes do linear interpolation movement, and it make tools do machining envelope movement along the surface of the workpiece, that formed envelope surface is the actual machining path. The normal direction distance between this envelope surface and the workpiece machining surface is called non-linear error[3]. In the interpolation program block, in Three-dimensional space the non-linear error model can be established, shown in Figure 1.

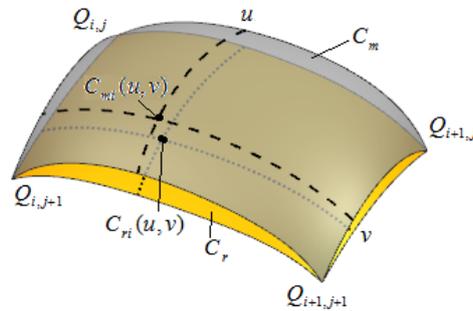


Fig.1. Nonlinear error model diagram

$C_{ri}(u,v)$ is any point on the C_r . Under the five-axis machine tool coordinate system, corresponding NC node $N_r(u,v) = [T_1, T_2, T_3, R_1, R_2]^T$ is five-dimensional column vector. Where, T represents translational movement of the translation axis, and R represents rotational movement of the rotation axis. Five-axis machine tool has three translational axes, two rotation axes.

After quadratic interpolation, motion vector of axes can be gotten at any NC node as follows:

$$N_m(u,v) = \begin{bmatrix} u & 1-u \end{bmatrix} \begin{bmatrix} N_{i,j} & N_{i,j+1} \\ N_{i+1,j} & N_{i+1,j+1} \end{bmatrix} \begin{bmatrix} v \\ 1-v \end{bmatrix} \quad (0 \leq u \leq 1, 0 \leq v \leq 1) \quad (1)$$

In the formula, $N_{i,j}$, $N_{i,j+1}$, $N_{i+1,j}$ and $N_{i+1,j+1}$ are five-dimensional column vector in tool coordinate system.

Between tool coordinate system and the workpiece coordinate system, the mapping relationship is formula (2).

$$\left. \begin{aligned} T_i &= \Phi_i(P,U) & i &= 1,2,3 \\ R_j &= \Psi_j(U) & j &= 1,2 \end{aligned} \right\} \quad (2)$$

In the formula, Φ_i and Ψ_j are reverse coordinate transformation mapping function of machine tool coordinate system and the workpiece coordinate system.

Between tool coordinate system and the workpiece coordinate system, the forward coordinate transformation mapping relations is formula (3).

$$\left. \begin{aligned} P &= \varphi(T_1, T_2, T_3, R_1, R_2) \\ U &= \psi(R_1, R_2) \end{aligned} \right\} \quad (3)$$

In the formula, φ and ψ are reverse coordinate transformation mapping function.

Therefore, insert u and v parameter values for the formula (1), can be calculated NC nodes-set in the actual machining, then use formula (3) to give the corresponding $C_{ri}(u, v)$ set.

All any point $C_{ri}(u, v)$ were masked operation, then the actual machining locus envelope surface C_r can be obtained (Figure 1). Assum that the point $C_{ri}(u, v)$ vertically projected onto the point $C_{mi}(u, v)$ of the surface C_m , then the nonlinearity error is formula (4).

$$\delta(u, v) = |C_{ri}(u, v) - C_{mi}(u, v)| \quad (4)$$

3 Compensation Strategy

3.1 Error Compensation Ideas

Using surface interpolation method, compensation point is inserted to the theoretical curve surface's u and v -parameter direction. Change the line spacing and step during CNC machining, and achieve to interpolate compensation point on the curve surface. In running of the tool axis vector, the tool axis vector will be always kept on sector surface boundary with start and end tool axis vector within the program block, and be maintained the tool axis vector velocity and acceleration continuity. Ultimate control tools smooth machining to achieve the purpose of reducing the nonlinearity error.

3.2.1 Interpolation point

As the literature[3] shows that the position of the maximum non-linearity error is close to the midpoint of the two tool cutting contacts points. Therefore, compensation point is Inserted in the midpoint of theoretical locus $C_{mL}(v)$. It is point $P_{m1}(x_h, y_h, z_h)$. As shown in Figure 2. After inserting the compensation

point, and then calculate the corresponding non-linear error value. If the errors is still beyond error range, continue to insert compensation point in this way, until meet the specified non-linear error range.

Thus, in addition to increasing the compensation point, we may consider reducing the spacing value in the U parameter direction. That is, compensation points are inserted in the U parameter direction. Theoretical locus curves are formed through the compensation point, curve $C'_{mL}(v)$ shown in figure 2. Then worked out the nonlinear error of the curve $C'_{mL}(v)$ and inserted the compensation point for the curve $C'_{mL}(v)$. Obtain coordinates position of the compensation points.

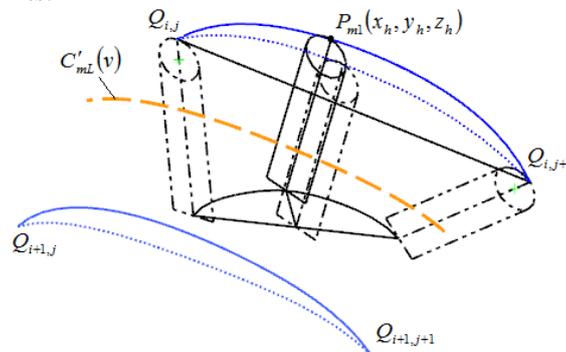


Fig.2 Non-linear error compensation

3.2.2 Determine the tool axis direction vector of compensation points

Here in A, C double turntable rotation axis is an example.

For the theoretical surfaces $C_m(u, v)$, if the fixed parameters u equals to u_0 , this surface becomes a unary function $C_m(u_0, v)$ about parameters v, called v-line. Similarly, if the fixed parameters v equal to v_0 , the partial derivative

vector $C_{mu}(u, v_0) = \frac{\partial C(u, v_0)}{\partial u}$ of u-line about parameters u called tangent

vector in the U-direction of u-line. Therefore, $C_{mv}(u_0, v) = \frac{\partial C(u_0, v)}{\partial v}$ is called

tangent vector in the V-direction of v-line. The unit normal vector $N_m(u_0, v_0)$ can be illustrated in the following formula:

$$N_m(u_0, v_0) = \frac{C_{mu}(u_0, v_0) \times C_{mv}(u_0, v_0)}{|C_{mu}(u_0, v_0) \times C_{mv}(u_0, v_0)|} \quad (5)$$

4 Simulation Analysis and Conclusions

For the machining of the fan blades, set the maximum allowable error, as shown in Figure 3, horizontal dashed line represents the maximum set point.

From the simulation experimental results, we can know, this algorithm can effectively reduce the nonlinearity error and achieve a smooth change of tool axis vector, and can improve the accuracy of five-axis NC machining. This verifies the effectiveness and practicality of the algorithm.

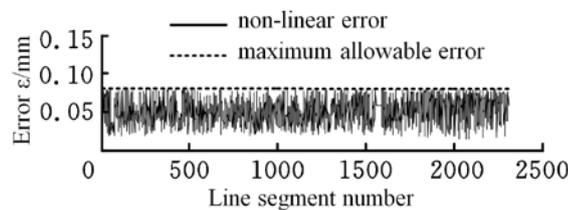


Fig. 3. Error control results after error control

References

1. Dai Ziyang, XIE Minghong. Analysis and Research of Five-axis Machining Nonlinear Error [J]. Machine Tool & Hydraulics, 2014, 42(11):70-73.
2. Yang Xujing, Zhou Yuansheng, Chen Zezhong, Wang Fulin. Analysis and Control of Tool Path Interpolation Error in Rotary Axes Motions of Five-axis CNC Milling [J]. Journal of Mechanical Engineering, 2012, 48(3):140-146.
3. Wu Dazhong. Nonlinear Error Control and Post-process in Five-Axis CNC Machining [D]. Shang Hai: Shang Hai Jiao Tong Univerisity, 2007.
4. Geng Cong, Yu Dong, Zhang Xiaohui, Five-axis CNC machining tool path control algorithm. China Mechanical Engineering, 2010,21 (24): 2904-2909.
5. Fan Liuqun, Qi Jingdang, Shen Bin, Zhu Zhihao, Plane Interpolation of Tool Orientation Algorithm for 5-axis Circumference Milling, Mechanical Engineering, 2011,47 (19): 158-162.