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Analysis of Error Compensation of Micro Four Axis CNC Milling Machine

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Abstract. The error compensation of Micro Four Axis CNC milling machine is mainly about the basic principle of error compensation and the realization of error compensation. It also analyzes the problems that should be paid attention to in error compensation, so as to improve the effect of error compensation. The method of superposition additional instruction and direct calculation for correcting NC instruction is expounded. According to the error modeling of the four axis CNC milling machine, the theoretical and practical relation between the tool path to the NC instruction, the theory and the actual relation of the NC instruction to the tool path are given by the direct calculation method, and the calculation of the actual numerical control instruction is made by using the relation formula, which provides the software compensation information for the micro four axis CNC milling machine.

1. An overview of error compensation

The error compensation technology has been applied to the machine tool in the last fifty years. In fact, the error compensation method has been used by the British Edward Troughton in the measurement of the repeatability positioning error of the guide rail before 1830, and the corresponding forms are made to make the error compensation for the data of these forms. With the method of error measurement and identification, the breakthrough progress and the rapid development of computer science and technology, the machine tool error modeling technology is becoming mature and the machine tool automation technology is gradually mature. These technologies provide the technical basis for error compensation. It is an inevitable trend to compensate for the increasingly complex structure of the workpiece, improve the machining precision and reduce the cost of production. It is an inevitable trend to compensate for the total efficiency of the CNC machine tools, especially the precision, ultra precision machine tools and micro manufacturing technology.

Error compensation technology allows the existence of machine tool error. By measuring and analyzing the cause of error formation and various errors of machine tools, the error model is used to compensate the motion of each system in order to eliminate or reduce the inherent error of the system to improve the precision of the machine tool.

The actual numerical control instruction is not equal to the ideal numerical control instruction. On the basis of the measurement error and the error modeling, the numerical control instructions are corrected, so that the cutting edge position of the tool is as close as possible to the ideal position, as shown in Figure 1.

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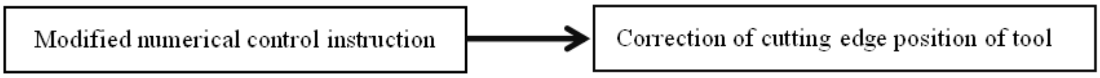


Figuer. 1 Correction of numerical control instruction

2. Classification of error compensation and forming motion of machine tools

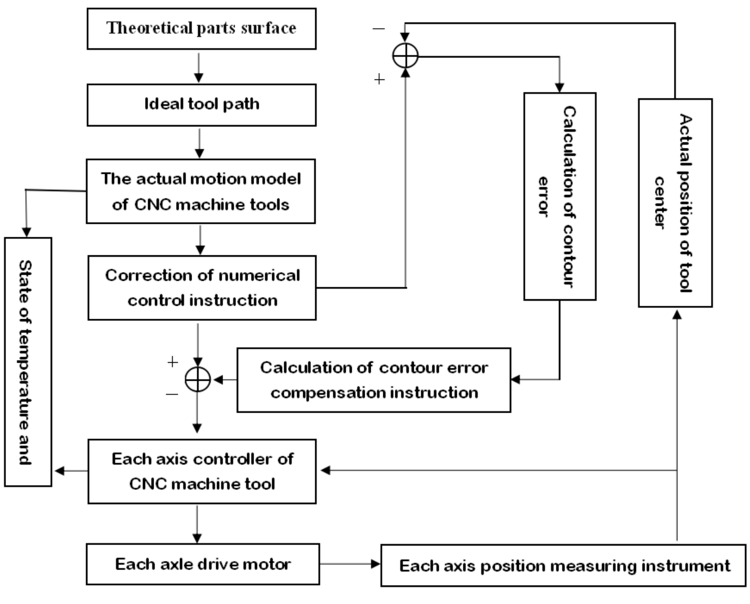
There are two basic methods to improve the accuracy of machine tools, such as error prevention and error compensation. Error prevention is to eliminate possible error sources in the process of design and processing. It is not easy to use error prevention to improve the machining accuracy of machine tools. Therefore, we should use error compensation to control errors. According to its characteristics, the types of error compensation can be divided into static compensation and dynamic compensation, real-time and non real time error compensation, hardware compensation and software compensation.

The forming process of NC machine tool means that the motion axis of machine tool follows the pre programmed driving instructions. The surface model of the workpiece theory is mapped into the process of tool path. According to the shape of the surface of the workpiece, the path of the tool is described, and the NC instruction of the motor motor is mapped, the NC instruction is input and the tool path is completed. Therefore, according to the error compensation classification in the process of forming, the forming motion of CNC machine tool can be divided into error free motion and error compensation motion.

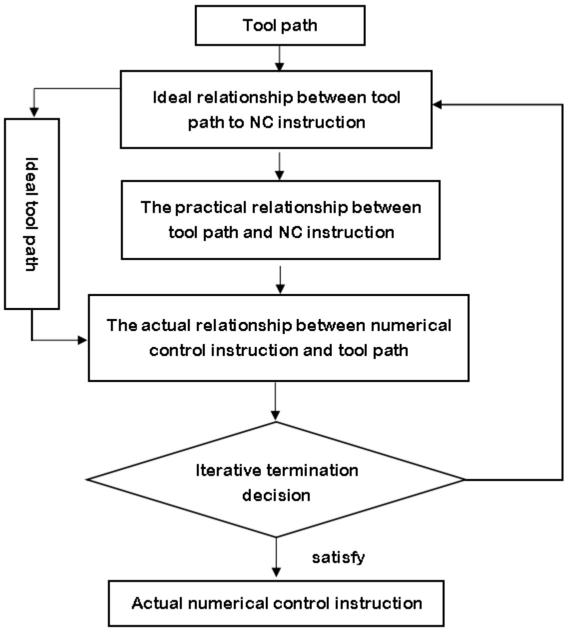
There are two ways to modify NC instruction. One is to directly calculate the actual NC instruction, the second is to add an additional instruction on the theoretical NC instruction. Many machine tools, especially the CNC machine tools for precision machining, often combine the two methods, which can make full use of the advantages of the two methods, and then improve the precision and quality of the processing. As shown in Figure 2, we combine the two methods.

3. Direct calculation of correction instruction for CNC Micro Four Axis CNC milling machine

The direct calculation method of NC instruction revision is directly calculating the actual instruction that can realize error compensation by determining the relation of mathematical models. According to the established model, we can establish the relationship between numerical control instruction, tool path and tool path, and then directly calculate the actual numerical control instructions. The direct algorithm process of the actual instruction of the NC four axis milling machine is shown in Figure 3.



Figuer 2. Sample forming motion control principle of double link error compensation software



Figuer 3. The flow of NC direct instruction algorithm for CNC micro grinder

The tool is usually in a coordinate system with the tool spindle, and the coordinates of the tool points in the tool coordinate system are:

$$P_t = [0\ 0\ t\ 1] \quad (1)$$

The coordinates of tool attitude vectors in tool coordinate system are:

$$V_t = [0\ 0\ t\ 0] \quad (2)$$

According to the motion relation model, the following direct calculation method is applied to modify the specific calculation process of NC instruction.

4. Tool route to NC instruction

4.1. Tool path

The tool path is based on the surface and processing strategy of the workpiece, which has been given. It is the source of the movement of the machine tool, and the tool path can be described as:

$$P_{line} = [p_{wx}\ p_{wy}\ p_{wz}\ 1]^T \quad (3)$$

Among them, pwx pwy PWZ is the coordinates of tool path in the W coordinate system of workpiece spindle, and it is related to the surface, machining mode and tool model of workpiece, it is known.

For numerical control four axis milling machine, there is still a problem of attitude. It is known that the attitude of the tool is known as the tool attitude route according to the surface of the work drawing and the processing method, and it is also known.

$$\vec{V}_{gesture} = [v_{wx} \quad v_{wy} \quad v_{wz} \quad 0]^T \quad (4)$$

Among them, vwx vwy vwz is the projection of the tool attitude route in the w coordinate system of the workpiece spindle, which is related to the workpiece drawing surface, the machining mode and the tool model. If the vector is taken, then the vwx vwy vwz is the direction cosine.

4.2. Ideal relationship between tool path to NC instruction

The ideal relation between tool path and NC instruction is obtained by modeling.

$$P_{wideal}=\left[\prod_{u=1}^{v}T_{L^u(k)L^{u-1}(k),p}T_{L^u(k)L^{u-1}(k),s}\right]^{-1}\left[\prod_{m=1}^{n}T_{L^m(j)L^{m-1}(j),p}T_{L^m(j)L^{m-1}(j),s}\right]P_t-P_{line}+P_{wideal}$$

The expansion calculation can be obtained:

$$V_{wideal}=\left[\prod_{u=1}^{v}T_{L^u(k)L^{u-1}(k),p}(R)T_{L^u(k)L^{u-1}(k),s}(R)\right]^{-1}\left[\prod_{m=1}^{n}T_{L^m(j)L^{m-1}(j),p}(R)T_{L^m(j)L^{m-1}(j),s}(R)\right]\vec{V}_t$$

$$-\vec{V}_{gesture}+\vec{V}_{wideal}$$

$$=\begin{bmatrix}\cos A & -\sin A & 0 & 0\\ \sin A & \cos A & 0 & 0\\ 0 & 0 & 1 & 0\\ 0 & 0 & 0 & 1\end{bmatrix}\begin{bmatrix}1 & 0 & 0 & 0\\ 0 & \cos C & -\sin C & 0\\ 0 & \sin C & \cos C & 0\\ 0 & 0 & 0 & 1\end{bmatrix}\begin{bmatrix}0\\0\\t\\0\end{bmatrix}-\begin{bmatrix}v_{wx}\\v_{wy}\\v_{wz}\\0\end{bmatrix}+\begin{bmatrix}\cos A\\0\\\cos C\\0\end{bmatrix}$$

4.3. The practical relationship between tool path and NC instruction

The actual relationship between tool path and NC instruction is:

$$P_w^{'}=\begin{bmatrix}p_{kx}^{'} & p_{ky}^{'} & p_{kz}^{'} & 1\end{bmatrix}^T=\left[\prod_{u=1}^{v}T_{L^u(k)L^{u-1}(k),p}T_{L^u(k)L^{u-1}(k),pe}T_{L^u(k)L^{u-1}(k),s}T_{L^u(k)L^{u-1}(k),se}\right]^{-1}$$

$$\left[\prod_{m=1}^{n}T_{L^m(j)L^{m-1}(j),p}T_{L^m(j)L^{m-1}(j),pe}T_{L^m(j)L^{m-1}(j),s}T_{L^m(j)L^{m-1}(j),se}\right]P_t-P_{line}+P_w^{'}$$

$$\vec{V}_w^{'}=\begin{bmatrix}v_{kx}^{'} & v_{ky}^{'} & v_{kz}^{'} & 0\end{bmatrix}^T$$

$$=\left[\prod_{u=1}^{v}T_{L^u(k)L^{u-1}(k),p}(R)T_{L^u(k)L^{u-1}(k),pe}(R)T_{L^u(k)L^{u-1}(k),s}(R)T_{L^u(k)L^{u-1}(k),se}(R)\right]^{-1}$$

$$\left[\prod_{m=1}^{n}T_{L^m(j)L^{m-1}(j),p}(R)T_{L^m(j)L^{m-1}(j),pe}(R)T_{L^m(j)L^{m-1}(j),s}(R)T_{L^m(j)L^{m-1}(j),se}(R)\right]\vec{V}_t-\vec{V}_{gesture}+V_w^{'}$$

4.4. Initial value calculation of actual numerical control instruction

The theoretical numerical control instruction is selected as the initial iteration value.

$$\begin{bmatrix} x_0 \\ y_0 \\ z_0 \\ 1 \end{bmatrix} = \left[\prod_{u=1}^{v} T_{L^u(k)L^{u-1}(k),p} T_{L^u(k)L^{u-1}(k),s}\right]^{-1} \left[\prod_{m=1}^{n} T_{L^m(j)L^{m-1}(j),p} T_{L^m(j)L^{m-1}(j),s}\right] \begin{bmatrix} 0 \\ 0 \\ t \\ 1 \end{bmatrix} - \begin{bmatrix} p_{wx} \\ p_{wy} \\ p_{wz} \\ 1 \end{bmatrix} + \begin{bmatrix} x_{wd} \\ y_{wd} \\ z_{wd} \\ 1 \end{bmatrix}$$

$$\begin{bmatrix} \cos C \\ 0 \\ \cos A \\ 0 \end{bmatrix} = \left[\prod_{u=1}^{v} T_{L^u(k)L^{u-1}(k),p}(R) T_{L^u(k)L^{u-1}(k),s}(R)\right]^{-1} \left[\prod_{m=1}^{n} T_{L^m(j)L^{m-1}(j),p}(R) T_{L^m(j)L^{m-1}(j),s}(R)\right] \begin{bmatrix} 0 \\ 0 \\ t \\ 0 \end{bmatrix}$$

$$- \begin{bmatrix} v_{wx} \\ v_{wy} \\ v_{wz} \\ 0 \end{bmatrix} + \begin{bmatrix} \cos C \\ 0 \\ \cos A \\ 0 \end{bmatrix} \qquad (5-$$

4.5. Iterative calculation of numerical control instruction

According to the calculation procedure of direct algorithm, the iterative calculation of NC instruction is as follows:

$$\begin{bmatrix} x_{k+1} \\ y_{k+1} \\ z_{k+1} \\ 1 \end{bmatrix} = \left[\begin{bmatrix} 1 & 0 & 0 & a_5 \\ 0 & 1 & 0 & b_5 \\ 0 & 0 & 1 & c_5 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & -\Delta\gamma_{xy} & \Delta\beta_{zx} & 0 \\ \Delta\gamma_{xy} & 1 & 0 & 0 \\ -\Delta\beta_{zx} & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \right.$$

$$\begin{bmatrix} 1 & 0 & 0 & x \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & \Delta\gamma_5 & \Delta\beta_5 & \Delta x_5 \\ \Delta\gamma_5 & 1 & -\Delta\alpha_5 & \Delta y_5 \\ -\Delta\beta_5 & \Delta\alpha_5 & 1 & \Delta z_5 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & a_6 \\ 0 & 1 & 0 & b_6 \\ 0 & 0 & 1 & c_6 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$\begin{bmatrix} 1 & -\Delta\gamma_{xC} & \Delta\beta_{xC} & 0 \\ \Delta\gamma_{xC} & 1 & 0 & 0 \\ -\Delta\beta_{xC} & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos C_k & -\sin C_k & 0 \\ 0 & \sin C_k & \cos C_k & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$\left. \begin{bmatrix} 1 & \Delta\gamma_6 & \Delta\beta_6 & \Delta x_6 \\ \Delta\gamma_6 & 1 & -\Delta\alpha_6 & \Delta y_6 \\ -\Delta\beta_6 & \Delta\alpha_6 & 1 & \Delta z_6 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & a_7 \\ 0 & 1 & 0 & b_7 \\ 0 & 0 & 1 & c_7 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & \Delta\gamma_7 & \Delta\beta_7 & \Delta x_7 \\ \Delta\gamma_7 & 1 & -\Delta\alpha_7 & \Delta y_7 \\ -\Delta\beta_7 & \Delta\alpha_7 & 1 & \Delta z_7 \\ 0 & 0 & 0 & 1 \end{bmatrix} \right]^{-1}$$

Iterative terminating conditions

$$\begin{cases} \left| p_{wxk} - p_{wxk-1} \right| \le \varepsilon_x \\ \left| p_{wyk} - p_{wyk-1} \right| \le \varepsilon_y \\ \left| p_{wzk} - p_{wzk-1} \right| \le \varepsilon_z \end{cases}$$

$$\begin{cases} \left| v_{wxk} - v_{wxk-1} \right| \le \delta_x \\ \left| v_{wyk} - v_{wyk-1} \right| \le \delta_y \\ \left| v_{wzk} - v_{wzk-1} \right| \le \delta_z \end{cases}$$

5. conclusion

This paper mainly studies the basic principle of error compensation and the realization of error compensation. The error compensation is divided into real time error compensation and non real time error compensation, static compensation method and dynamic compensation method, and hardware compensation and software compensation according to different conditions. It also analyzes the problems that should be paid attention to in error compensation, so as to improve the effect of error compensation. The superscript additional instructions and direct calculation methods for correcting NC instructions are expounded. According to the error modeling of numerical control four axis NC milling machine, using direct calculation method, the theory and actual relation of tool path to NC instruction, theory and actual relation of NC instruction to tool path are given, and the calculation of actual numerical control instruction is made by using the relation formula, which provides software for CNC four axis milling machine. Compensation information.

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