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Research on tool cutting trajectory based on curve fitting algorithm

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Abstract: *In order to achieve a composite plate to take the internal core plate process, it is necessary to remove the external steel sleeve by cutting tools, and ensure the integrity of the internal core plate. In this paper, from the composite plate shape size, through the sensor to collect composite plate shape bending data and storage. In order to make the cutting process of the tool as smooth as possible and make the impact force on the tool as small as possible, the curve fitting algorithm is used to fit the bending degree data of the composite plate shape into a smooth polynomial function curve, and the smooth discrete points are obtained according to the fitted polynomial function. Then, the NC profiling of the tool is realized by the linear interpolation of the three-axis servo motor. The results show that the method can protect the tool and prolong the tool life.*

Keywords: *Composite plate; sensor; curve fitting; linear interpolation*

1. Foreword

A precious rare metal material cannot contact with air during the processing of the metal. It will be made into a composite plate during production [1]. The composite plate is composed of a rare metal core in the core, two layers of steel plates and surrounding steel frames. The components are metallurgically bonded through high-temperature hot rolling to form a sandwich-like structure. After processing is completed, the internal core plate is completely removed. The location of the inner core plate of the composite plate and the size of the steel sheet and the steel frame are shown in Figure 1.

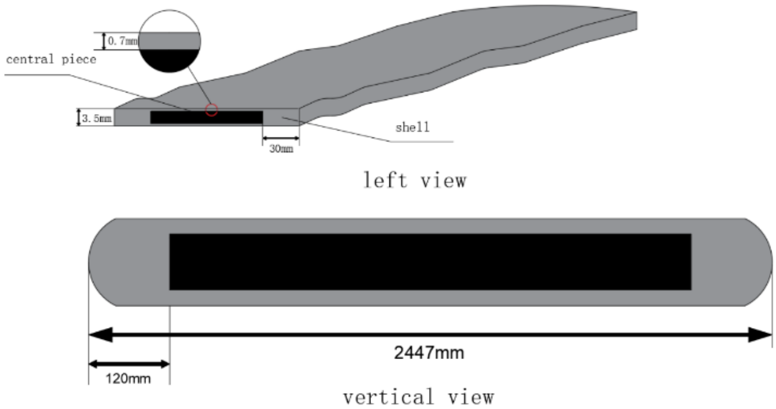

Figure 1: Internal core plate position diagram

2. Overall scheme of tool cutting path optimization

Because the composite plate is hot rolled during the processing, the shape of the composite plate is deformed. After the composite plate is fixed on the machine tool, it still presents irregular wave-shaped curves in the length direction and the width direction. The comparison between the curvature of each curve and the thickness of the steel skin is shown in Table 1. Therefore, in order not to hurt the core plate only cut through the skin, the tool position cannot be fixed for processing, which can easily lead to uneven cutting depth, damage to the internal core plate, uneven force of the tool, and tool breakage[2]. In this paper, the original information of the object is measured by synchronous pre-scanning of the thickness and width bending of the sensor every 1cm, and the discrete points reflecting the bending of the

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composite plate are obtained. In order to make the tool cutting process as smooth as possible, the curve fitting algorithm is used to process the discrete points, and the smooth polynomial function curve is obtained. According to the curve, the smooth discrete points are obtained as the cutter coordinates of the servo motor, and the three-axis servo tool holder is controlled[3]. The linear interpolation cutter is used to realize the profiling cutting of the tool.

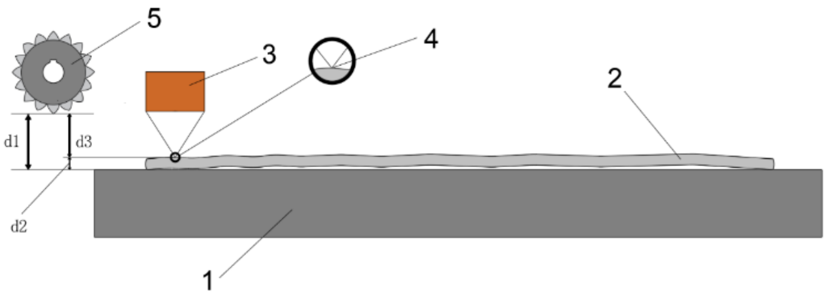
Table 1: Curve curvature (peak-valley height difference) unit: mm

Steel skin thickness	Thickness to curvature	Bending in width direction
0.7	3.0	2.5

3. Data acquisition and coordinate conversion

3.1 Thickness data acquisition and tool coordinate conversion

In this paper, the non-contact laser displacement sensor HG-C1050 is used to collect the bending degree of the thickness direction. The range of the sensor is 30 mm, and the collection range is 50 ± 15 mm. The sensor takes the machining table as the zero point, and the laser is irradiated to the composite plate. The analog value of the point can be returned in real time. The actual height value of the point can be obtained after the conversion of the analog value by PLC, and then the tool can be calculated according to the distance between the tool vertex and the table. The coordinates of the tool at the collection point are shown in Figure 2. The tool setting distance d1 minus the laser acquisition distance d2 can obtain the distance d3 from the tool to the plate, and the depth of the workpiece can obtain the lower tool coordinate of the acquisition point. The sensor scans once along the length of the workpiece to obtain the thickness to all the lower tool coordinate discrete points.



1processing platform 2compound board 3HG-C1050 4Laser acquisition point 5cutting tool

Figure2: Thickness data acquisition and conversion relationship diagram

3.2 The relationship between data acquisition and conversion in width direction

In this paper, the width direction curvature acquisition uses a contact self-compound displacement sensor. The sensor is composed of a resistance ruler and a signal transmitter. The resistance ruler has a range of 50 mm, and the preloaded spring body is between 15 mm and 20 mm after installation. When the resistance ruler contacts the edge of the composite plate, the current compression amount L2 at this position can be converted in the PLC according to the analog value returned by the transmitter, and then the initial preload L1 can be subtracted to obtain the curvature value at this position. The width direction curvature acquisition and conversion relationship is shown in Figure 3. It can be seen from Fig.3 that when the resistance ruler moves horizontally along the side of the plate, all the compression values of the width of the composite plate can be collected, and the discrete points of the undercut coordinates of the width to all positions can be obtained.

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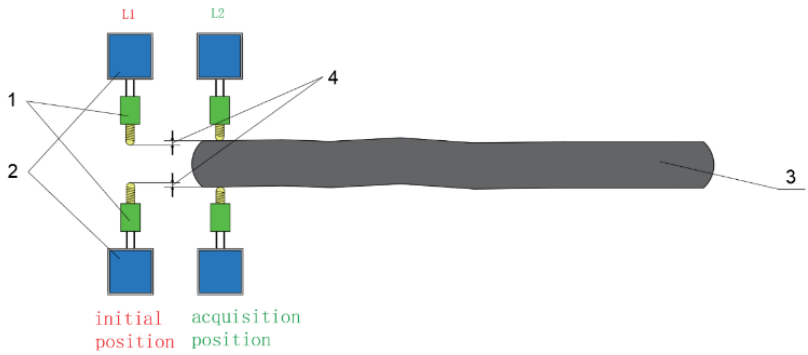

1Resistance ruler displacement sensor 2Signal converter 3Compound board 4Collect compression amount

Figure 3: Schematic diagram of data acquisition and conversion relationship in width direction

4. Curve fitting algorithm

4.1 Least squares curve fitting algorithm

Due to the error in the actual data acquisition, some data deviation is too large, need to use the optimization algorithm, to optimize the collected data processing, according to the new data fitting processing.

For a set of discrete points $\{(x_i\ y_i), i = 0,1,2,\ldots,m$, based on the least square principle, the functional relationship f (x, A) , between variables x and y is obtained, so that it can best approximate or fit the known data . f (x, A) is called the fitting model, and $A = (a_0, a_1, \ldots, a_n)$is some undetermined parameters. The method is to determine the parameter A so that the weighted sum of squares of the residuals $e_k = y_k - f(x_k, A)$of the fitting model and the actual measured discrete points at each point is minimized, and the fitting effect is considered to be the best[4].

4.2 Polynomial least mean square fitting

Fitting model$f(x, A) = a_0 + a_1 x + \cdots + a_n x^n$

It is called polynomial fitting ream

$$\varphi(a_0, a_1, \ldots, a_n) = \sum_{i=0}^{m} e_i^2 = \sum_{i=0}^{m}(a_0 + a_1 x_i + \cdots + a_n x_i^n - y_i)^2$$

The minimum is:

$$\frac{\partial\varphi}{\partial a_j} = 2\sum_{i=0}^{m} x_i^j (a_0 + a_1 x_i + \cdots + a_n x_i^n - y_i) = 0, j = 0,1,2,\ldots,n$$

That is : $\sum_{i=0}^{m}\left(a_0 x_1^j + a_1 x_i^{j+1} + \cdots + a_n x_i^{j+n}\right) = \sum_{i=0}^{m} x_i^j y_i$

Equations can be obtained:

$$\begin{bmatrix} m+1 & \sum_{i=0}^{m} x_i & \cdots & \sum_{i=0}^{m} x_i^n \\ \sum_{i=0}^{m} x_i & \sum_{i=0}^{m} x_i^2 & \cdots & \sum_{i=0}^{m} x_i^{n+1} \\ \cdots & \cdots & \cdots & \cdots \\ \sum_{i=0}^{m} x_i^n & \sum_{i=0}^{m} x_i^{n+1} & \cdots & \sum_{i=0}^{m} x_i^{2n} \end{bmatrix} \times \begin{bmatrix} a_0 \\ a_1 \\ \vdots \\ a_n \end{bmatrix} = \begin{bmatrix} \sum_{i=0}^{m} y_i \\ \sum_{i=0}^{m} x_i y_i \\ \vdots \\ \sum_{i=0}^{m} x_i^n y_i \end{bmatrix}$$

This equation set is called the normal equation of polynomial fitting. Let

$$X=\begin{bmatrix} m+1 & \sum_{i=0}^{m} x_i & \cdots & \sum_{i=0}^{m} x_i^n \\ \sum_{i=0}^{m} x_i & \sum_{i=0}^{m} x_i^2 & \cdots & \sum_{i=0}^{m} x_i^{n+1} \\ \cdots & \cdots & \cdots & \cdots \\ \sum_{i=0}^{m} x_i^n & \sum_{i=0}^{m} x_i^{n+1} & \cdots & \sum_{i=0}^{m} x_i^{2n} \end{bmatrix} \quad Y=\begin{bmatrix} \sum_{i=0}^{m} y_i \\ \sum_{i=0}^{m} x_i y_i \\ \vdots \\ \sum_{i=0}^{m} x_i^n y_i \end{bmatrix} \quad A=\begin{bmatrix} a_0 \\ a_1 \\ \vdots \\ a_n \end{bmatrix}$$

It can be concluded that XA = Y, so that the coefficient matrix A = X ^ (-1) Y can be obtained, and finally the parameters to be determined are determined, and the fitting curve is obtained.

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4.3 Composite plate thickness bending discrete point least squares fitting

The scatter diagram of the lower tool coordinate collected and converted according to the curvature of the thickness direction is shown in Fig. 4. It can be seen from Fig. 4 that the trend of the scatter plot of the undercut directly reflects the bending degree of the thickness direction of the composite plate. The points of the discrete point image are not connected to a smooth curve. The undercut directly according to the discrete point is likely to cause the tool to be subjected to too much impact force, resulting in a decrease in tool life or even direct fragmentation of the tool.

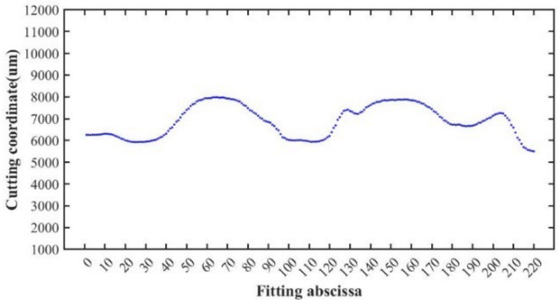
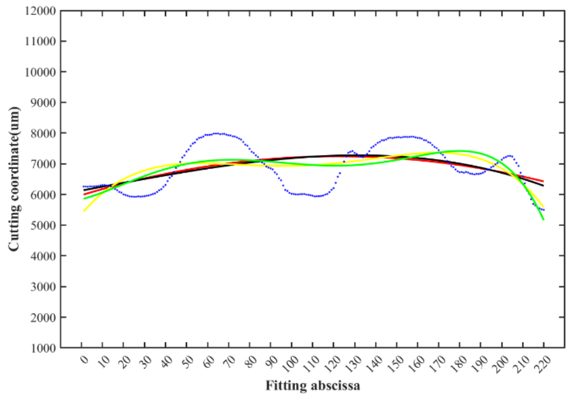


Figure 4: Scatter plot of thickness downward cutter coordinate

The length of the material plate is 2.44 meters, and the remaining 2.2 meters are removed from the 0.24 meters without the core plate at both ends. A total of 220 points are collected every 1cm. The least squares fitting effect of discrete points is shown in Figure 5.



Red-second-order polynomial fitting curve Black-third-order polynomial fitting curve Yellow-fourth-order polynomial fitting curve Green-fifth-order polynomial fitting curve

Figure 5: Least squares fitting diagram

According to the analysis of Figure 6, it is difficult to obtain a better fitting curve for all discrete points by using this method regardless of several order fitting. The reason is that the collected discrete point changes are too complex, and it is difficult to find a function curve discrete points. The solution to this problem is piecewise fitting. After a lot of experimental analysis, 10 points are selected to fit the third-order polynomial. The piecewise fitting effect is shown in Figure 6.

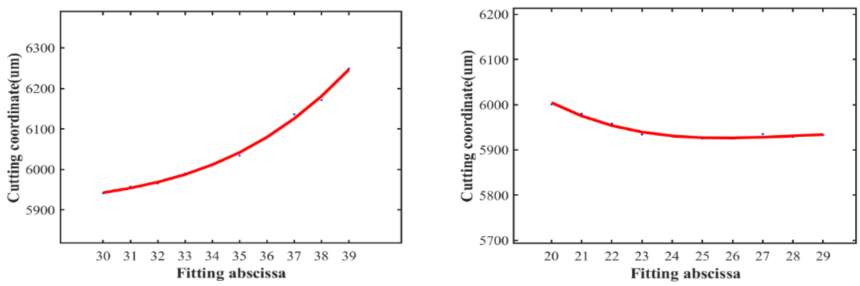


Figure 6: Segmented fitting effect diagram

It can be seen from Figure 6 that the fitting function obtained by fitting 10 points once can highly

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reflect the trend of discrete points and obtain smooth fitting curves. The smooth curves are shown in *Figure 7 in the same coordinate system.*

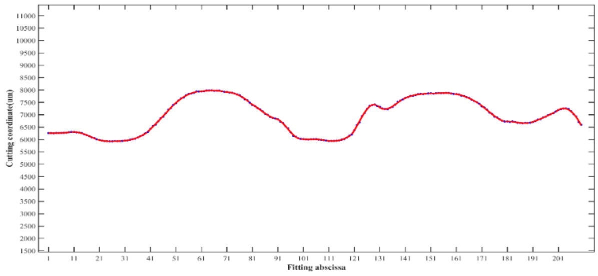

Figure 7: Sectional fitting set diagram of discrete points in thickness direction

It can be seen from Figure 7 that the piecewise fitting curve can reflect the trend of the discrete point and the fitting curve is smooth without mutation. The curve can be used to determine the undercut coordinate.

The undercut coordinate in the width direction is the same as the undercut coordinate in the thickness direction. The smooth discrete point coordinate obtained after the solution is completed is used as the undercut coordinate of the servo motor to control the three-axis servo turret to achieve profiling cutting.

5. Three axis linear fitting

5.1 Interpolation device

The interpolation device is a key component in the whole CNC system. In the process of CNC machining, it is necessary to control the tool along the specified path movement, cutting the workpiece contour, and to ensure the accuracy and surface quality of each point in the cutting process, which depends on the interpolation performance of the CNC system. The CNC machine tool moves and cuts the tool according to the trajectory of the interpolation device[5].

5.2 Three axis linear interpolation

For the linear machining trajectory, because of its simple line type, the linear direct fitting method can be used for interpolation operation. By forming a three-axis linkage of the XYZ axis table, the motion synthesis is used to directly fit the straight-line machining trajectory, thereby avoiding the ridge phenomenon caused by the broken-line fitting. As shown in Figure 8, assuming that AB two points are the discrete points after curve fitting, the tool path moves straightly from point A to point B, and the synthetic motion of XYZ three axes is required to be consistent with the machining path. As shown in the figure, V is the actual feed speed of the tool, V x, V y , V z are the three-axis servo feed speed respectively, ΔX, ΔY and ΔZ are the motion distance of the three-axis servo respectively, and the total displacement $S = [(\Delta X)^2 + (\Delta Y)^2 + (\Delta Z)^2]^{\frac{1}{2}}$ can be obtained. $V_x = V * \frac{\Delta X}{S}$, $V_y = V * \frac{\Delta Y}{S}$, $V_z = V * \frac{\Delta Z}{S}$. In the interpolation motion, in order to achieve the three axis from point A to point B at the same time, it is necessary to match the speed. It is not difficult to obtain that the ratio of the three axis speed is equal to the ratio of the displacement, that is, $\frac{\Delta X}{V_x} = \frac{\Delta Y}{V_y} = \frac{\Delta Z}{V_z}$. The interpolation method used in this paper is to ensure that the X-axis moves at a constant speed, that is, the collected data and the interpolation program are kept at the same speed, that is, Vx and Δ X are fixed values, and the speed of the X-axis is matched with the speed of the YZ axis. ΔY and ΔZ are determined by the coordinate difference of discrete points, that is, $V_y = \frac{Vx*\Delta Y}{\Delta X} = \frac{Vx(Y_1-Y_0)}{X_1-X_0}, V_z = \frac{Vx*\Delta Z}{\Delta X} = \frac{Vx(Z_1-Z_0)}{X_1-X_0}$.

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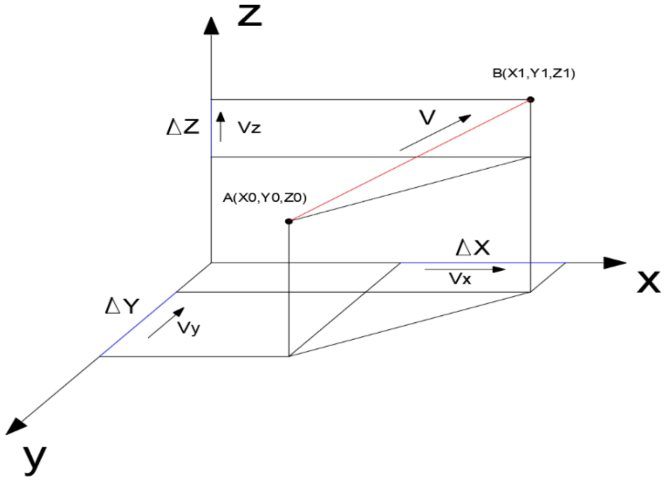

Figure 8: XYZ three-axis linear interpolation

6. Tag

The curve fitting algorithm is used to optimize the cutting path of the tool to protect the tool, and the cutting process is stable without jitter, and the cutting depth is basically the same, which can complete the more complex cutting path optimization and prolong the service life of the tool.

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