Parametric Design of NC Tangency Point in Archimedes spiral Helical surface

Kang Qiyue¹,a, Gao Baizhan²,b
¹,²Xi’an Research Institute of China Coal Technology and Engineering Group, Xi’an, shaanxi, China
ªemail: kangqiyue@ctctegxian.com, bemail: gaobaizhan@ctctegxian.com

Abstract: This article based on matlab secondary development on the surface of the archimedean spiral cut NC contacts of parametric design. The generation principle of the spiral surface is described, and the processing error that may be caused by the processing method of the spiral surface is analyzed. In the case of meeting the processing requirements, a larger step length and a larger path distance are selected to calculate the tangent contact points of the spiral surface for CNC machining, and the accuracy of the contact points is verified by Matlab. Finally, a parametric design is carried out for the processing of the spiral curved surface tangent contact.

1. Introduction
The archimedes spiral surface is a common surface, widely used in parts such as threads, worms, tools, tie blades, and some archimedes spiral surfaces, such as the spiral surface used for the propeller spiral blades. Generally, the outer diameter of the curved surface, the internal and outer diameter is large, and the label is large, and there is no ready-made special tool, so its processing is large. However, with the development of CNC technology and the industry's requirements for archimedes spiral curved surface processing accuracy, CNC machine tool processing archimedes spiral surface will inevitably get a wide range of applications, this article is in aquimed on the basis of the mathematical model, the CNC machining and cut contacts of the aquimed screw surface are explored and studied.

2. Archimedes spiral mathematical model
The bus is moved along a cylinder or elliptical column spiral[1]. And always intersect with the cylindrical axis, formed as a spiral surface, as shown in Figure 1. The Archimedes spiral Formation is:

\[
\begin{align*}
    x &= \rho \cdot \cos \theta \\
    y &= \rho \cdot \sin \theta \\
    z &= \rho \cdot \theta - \rho \cdot \tan \alpha
\end{align*}
\]

among them, \(\rho = \frac{d}{2\pi}\), \(d\) is the lead, \(\alpha\) is the profile angle of the cutting edge (usually take \(\alpha = 20^\circ\)). In the formula, the "—" sign is used on the left side of the right-handed helix, when used on the right side of a right-handed helix, it is a "+" sign.
3. Planning of Archimedes Spiral Cut Contacts
Cutting Contact Point, abbreviation CC-Point, refers to the theoretical contact point between the curved surface of the processed workpiece and the tool during processing. The two goals of cutting tool contact planning are to reduce machining time and improve machining accuracy, these two goals are mutually restricted. When reducing the line spacing and cutting step length, although the machining quality and machining accuracy of the workpiece are improved, the machining efficiency is significantly reduced. Generally, the numerical control machining of the curved surface is a given one. Fixed-value cutting step and line spacing. The disadvantage of this method is that it does not take into account the large machining error caused by the mutual movement of the tool and the workpiece during CNC machining. Therefore, in order to obtain a reasonable contact point, the planning of the contact point should be considered on the premise of ensuring that the machining accuracy requirements are met, choose a larger step length and distance as much as possible to significantly improve the machining efficiency.

3.1. Step length calculation
The step length refers to the distance between two adjacent contact points on the same tool processing path. The tool path of curved surface processing is a complex curve, which is theoretically an envelope formed by the relative movement of the tool on the curved surface. In CNC, the processing of the curve is approximated by linear interpolation by the machine tool, and then linearized by the CNC machine tool. The movement is approximated as a circular arc contour, so there must be machining errors in the machining process. Too large a step length will reduce the accuracy of contour approximation, increase the workload of subsequent processing, and reduce the overall processing efficiency. Too small a step length will increase the amount of cutting and reduce the programming efficiency, thereby reducing machining efficiency; therefore, determining a reasonable step length is an important issue for planning tool trajectories.

In multi-axis CNC machining, the tool uses linear interpolation as its movement mode, so there is an approximation error between the surface of the machined surface and the envelope formed by the tool movement. When the ball-end milling cutter performs linear interpolation along a certain curve on the machined surface, the local geometric relationship between the tool and the machined surface is approximately as shown in Figure 2.

![Figure 1 Archimedes spiral surface](image-url)
From the geometric relationship between the tool feed compensation and the given machining error, it can be obtained:

\[ \delta \leq \frac{1}{8} k_f (\Delta s)^2 \]  

(2)

- \( k_f \) — Curved curvature of the machined surface along the cutting feed direction
- \( \Delta s \) — The arc length of the machined surface in the inspection section

For any given error limit, when:

\[ \frac{1}{8} k_f (\Delta s)^2 \leq \varepsilon \]  

(3)

I.e. solve the step length, as shown in the following formula:

\[ \Delta s \leq 2 \frac{\varepsilon}{\sqrt{|k_f|}} \]  

(4)

### 3.2. Travel distance calculation

The cutting distance refers to the shortest line distance between two adjacent rows of tool paths. It is one of the important factors that affect the processing efficiency and the accuracy of the processed workpiece\(^3\). Its size will affect the size of the residual height. When the cutting distance is too large, the surface residual height of the processed surface will increase, which will increase the follow-up process and increase the production cost; if the cutting distance is too small, it will cause the increase in the number of passes increases the processing time, increases the amount of programs, and reduces the production efficiency. When the ball end milling cutter processes the curved surface, the tool radius and the residual height are closely related\(^4\), as shown in Figure 3.

![Figure 3](image_url)
When the ball-end milling cutter is processing the curved surface, the tool marks constitute the residual height between the cutting lines. As shown in Figure 3, the geometric relationship between the cutting line distance and the machining error can be obtained as the mathematical relationship between the cutting line width and the residual height:

\[
h = R \left( 1 - \sqrt{1 - \left( \frac{d}{2R} \right)^2} \right) + \frac{1}{2} k_b \left( \frac{d}{2} \right) \tag{5}\]

When \( e_b \) the maximum residual height is given, the width of the cutting line can be obtained by the following formula:

\[
d \leq 2 \sqrt{\frac{2Re_b}{1 - Rk_b}} \tag{6}\]

\( R \) — Tool radius
\( k_b \) — Curved curvature of the machined surface along the feed direction of the cutting line

### 3.3. Calculation of contact points

The method for solving the tangential contact point of spiral surface NC machining is as follows:

1. Define the array \((x_i, y_i)\), \((X_{i,j}, Y_{i,j}, Z_{i,j})\), and write the initial endpoint coordinate value of the end curve to the initial point \((x_0, y_0)\) \[5\];
2. Calculate the maximum normal curvature of the end curve (helix) \(k_b(k_f)\), and calculate the cutting step \(d\) (Walking step \(\Delta s\));
3. Find a point on the end curve \((x_i, y_i)\) satisfies \(\sqrt{(x_i - x_{i-1})^2 + (y_i - y_{i-1})^2} \leq d\);
4. Judgment \((x_i, y_i)\) whether it exceeds the boundary of the end surface curve, if it exceeds, the program will stop, if it is within the required range of the end surface curve, it will continue to run downwards;
5. So that in the conical spiral \(r_i = \sqrt{x_i^2 + y_i^2}\) calculate the spiral curve parameter equation \(L_i\);
6. Write the initial point coordinate value of the spiral curve \((X_{i,0}, Y_{i,0}, Z_{i,0})\), find a point on the spiral curve \((X_{i,j}, Y_{i,j}, Z_{i,j})\) to meet the condition\[6\]:

\[
\sqrt{(X_{i,j} - X_{i,j-1})^2 + (Y_{i,j} - Y_{i,j-1})^2 + (Z_{i,j} - Z_{i,j-1})^2} \leq \Delta s
\]

7. Judgment \((X_{i,j}, Y_{i,j}, Z_{i,j})\) whether it exceeds the boundary point of the spiral curve, if it is not exceeded, continue(6), and will \((X_{i,j}, Y_{i,j}, Z_{i,j})\) output, if the spiral curve is no longer required to continue(3).

Based on the above principles, by matlab perform a simulation analysis of a set of data, control the limit processing error within 0.1mm, the data of the contact point is calculated as shown in Figure 4, and the data graph is shown in Figure 5.
4. Parametric design of tool position point calculation
In order to facilitate the designer to carry out the parametric design and simulation analysis of the archimedes spiral surface, based on the graphical user interface (GUI) provided by the matlab software, a system designed specifically for the parameterization of the archimedes spiral knife position can be developed[7]. For this system, the key to the development is the design of the man-machine communication window. The following points should be paid attention to during the design of the man-machine interface: consistency, flexibility, interactivity and reliability. Based on the requirements of the simulation platform function, the form should contain options for users to choose or input boxes for inputting information and corresponding text descriptions. In addition to the basic controls mentioned above, the aesthetics and operability of the involved windows should also be considered. In addition, the form should be as simple, intuitive and comprehensive as possible in the design process, with few levels and clear[8].

Based on the above principles, the menu of the main window of the developed system mainly includes: the input of each processing parameter of archimedes spiral surface, the drawing of spiral groove surface and the output of cutting point, etc. The composition and function of the main menu are as follows: the input field of each processing parameter of the archimedes spiral surface, including the inner diameter, outer diameter, lead, helix angle of the archimedes spiral surface, and the tooth profile.
angle of the cutting edge, for input the parameters of the archimedes spiral surface. The spiral surface column is mainly used to draw the spiral surface through the inputted processing parameters of the archimedes spiral surface. The tangential contact point column displays the calculated tangential contact point in this column. Set the limit machining error, enter the parameters corresponding to the spiral line to be processed, and click "Draw" to get to the corresponding surface graphics, and the corresponding tool position points are shown in Figure 6.

Figure 6 Parameterized design of tool position

5. Conclusions
Since archimedes spiral surface processing is more complicated, the machining accuracy has a greater impact on future use, so reasonable modeling of spiral surface can effectively increase the service life and reduce production costs. Based on the analysis of the mathematical model of the archimedes spiral surface, this paper calculates the tangent contact points of the spiral surface, which provides a way of thinking for the future processing of the archimedes spiral surface. In the calculation process, the matlab in the secondary development, a set of procedures is designed to perform parametric design for the solution of the tangent contact, and the corresponding excision points can be obtained for the archimedes spiral surfaces of different specifications.

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