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Research on Numerical Control Programming of Honeycomb Core Materials Based on Ultrasonic Vibration Cutting

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Abstract

The excellent condition of NC program directly determines the quality and manufacturing efficiency of the product. It is one of the key links in the ultrasonic vibration cutting technology of Nomex honeycomb core, a typical composite material, which involves the formulation of the program, the selection of processing parameters, the planning of the tool path, the post-position and other content. However, due to the particularity of the application filed and the particularity of its CNC machines and tools, domestic CNC programming is still in the initial stage of exploration and experience accumulation. Therefore, in order to realize the high-quality and high-efficiency processing of honeycomb core material parts and give full play to the advanced processing technology and equipment, technical problems, such as difficult to controlling the tool over-cutting, tool interference and tool edge angle In the current numerical control programming, were researched, and the equivalent cutting tools in the programming were established. The generation of NC ultrasonic vibration cutting machining trajectory and the control of tool attitude were explored, and the difficulty of NC programming was given in combination with the actual working conditions, which lays the foundation of efficient and concise CNC machining program.

Keywords

Numerical control programming, equivalent cutting tool, tool attitude.

1. Introduction

With the development of aviation equipment technology, higher requirements are put forward for the performance of aviation equipment, and a large number of new high-performance materials have been introduced. Composite materials have been widely used in the new generation of aviation equipment by virtue of their unique advantages[1-2] , Especially the honeycomb core material, it plays an important role in improving the performance of aircraft, and is one of the key application technologies in the lightweight manufacturing of aircraft. The CNC machining technology of its honeycomb core parts has also become a measure of a country’s aircraft manufacturing capacity. One of the signs. However, due to the particularity of the honeycomb core material's spatial structure and cutting mechanism, it exhibits low processing efficiency, poor processing quality, high processing cost, and serious environmental pollution in the traditional processing process, which has become a constraint on the rapid equipment of composite components. Application bottleneck[3].

In order to improve the problems faced in the processing of honeycomb core parts, ultrasonic vibration cutting processing technology came into being with its unique advantages. Ultrasonic vibration cutting technology applies ultrasonic vibration to the cutting tool along its axial direction during the processing of honeycomb core parts, so that the contact state and mechanism of the tool and the processed material are changed, and finally through mechanical cutting, high-frequency micro-impact, and hollow Chemical effect to remove material. Compared with high-speed milling, this machining method has significant advantages in terms of machining accuracy, quality, efficiency and environmental friendliness. However, the current domestic research on CNC ultrasonic cutting technology is still basically at the stage of using and learning foreign equipment, lacking systematic theoretical and practical guidance, and there are still many problems to be overcome before practical applications, including ultrasonic vibration cutting of honeycomb core parts. CNC programming technology, due to the particularity of the application field, the processing technology data is blocked by foreign countries; due to the particularity of the machine tool and cutting tools, the phenomenon of tool overcutting, lacking, and tool interference appears in the CNC programming, and the ultrasonic vibration cutting of honeycomb core parts The research on programming technology is only the domestic Hafei company Zhang Yongyan and others based on CATIA programming software, and according to the common operating instructions of ultrasonic cutting machine tools, research on the precautions in CNC programming [4]; Chengfei company Li Yu et al. aimed at dagger tools The over-cutting, cutting residue and other problems in the cutting process, through the analysis of the tool structure, the tool cutting error model was established [5]; Chen Senyan and Liu En of Hangzhou Dianzi University started from the structural characteristics of the honeycomb material and the principle of ultrasonic vibration cutting to study The ultrasonic cutting process path of honeycomb core parts, and its machining error has been analyzed, calculated and compensated [6-7]. To sum up, the current CNC programming for honeycomb core parts is only in the preliminary stage of exploration and experience accumulation. Only specific parts can be selected based on experience to select process parameters and CNC programming. Therefore, it is impossible to give full play to the advantages of advanced processing technology and equipment. , Facing problems such as unstable processing quality, low production efficiency and insufficient production capacity.

Therefore, this article is based on actual working conditions, in view of the difficulties encountered in the CNC programming of honeycomb core parts, by analyzing the existing programming software and tool structure, the equivalent cutting tool in the programming is established, based on the section method and the surface of the honeycomb core material part. Characteristic analysis, research on the generation of CNC ultrasonic cutting processing trajectory and the control of tool posture, lay the foundation for the generation of accurate, efficient, and concise CNC machining programs, and at the same time provide references for engineering and technical personnel in this field.

2. Programming tool for ultrasonic vibration cutting of honeycomb core material

2.1. Dagger knife

The dagger knife is used as a rough machining tool for honeycomb core composite materials, and it needs to cut the thickness and width of the disc tool on the to-be-processed layer of the part. During the machining process, the main shaft of the machine tool does not rotate, and the cutting edge direction of the tool is controlled by the B axis to realize the rapid cutting of honeycomb core material.

Due to the special structure of the dagger knife, the current CATIA, UG and other commercial programming software do not have the corresponding functions to complete the preparation of the cutting program. At the same time, the programming software will consider the processing tool as a rotating body during the programming process. Then according to the tool shape and size set by the user and the theoretical model of the part, the driving geometric parameters are provided, and the machining tool path is calculated. However, the shape of the dagger tool is not a rotating body, so in the programming process, a cylindrical shape with a diameter of the bottom edge width L0 of the tool needs to be established as the equivalent tool of the dagger tool. The schematic diagram of the equivalent tool is shown in Figure 1.

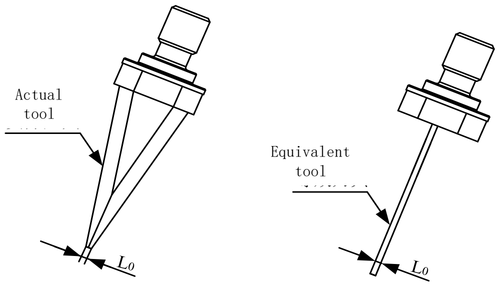

Figure 1 Schematic diagram of the equivalent tool of the dagger knife

2.2. Disc cutter

Disc cutters are mainly used for surface forming of parts, that is, according to the path cut by the dagger cutter, the required part profile is processed to meet the final required shape and quality of the workpiece. Ultrasonic vibration cutting disc cutters are essentially different from high-speed cutting honeycomb milling cutters. Disc cutters have no crushed bodies. They use their sharp cutting edges to process honeycomb core parts under the conditions of high frequency and small amplitude. In order to ensure the accuracy of the interference check and the simulation display in the processing of the disc tool, we equivalent to the tool with crushed body under the condition of the tool diameter unchanged, as shown in Figure 2.

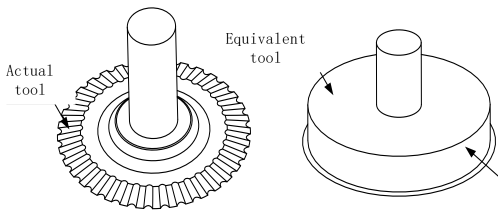

Figure 2 Schematic diagram of equivalent tool for disc cutter

3. Method for generating ultrasonic vibration cutting track of honeycomb core material

The cutting trajectory is generated by calculating the tool position according to certain rules according to the selected machine tool, cutting tool, cutting method and machining allowance through the geometric model of the part [8]. For the generation of ultrasonic vibration machining path and trajectory of honeycomb core parts with complex profiles, accuracy and efficiency are two main issues that need to be considered. The step length interpolation error of the cutting path and the machining accuracy are related to the residual height between the line spacing; the machining efficiency is related to the complexity of the product and the tool path generation method, so the programmer must seek a reasonable tool path generation algorithm before the step programming, Obtain the highest processing efficiency under the premise of ensuring the processing quality.

At present, the commonly used tool path generation methods include parameter method, equal residual height method, equal section plane method and space filling method. Although the calculation of the isoparametric method is simple and feasible, the problems of tool position

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redundancy and lack of tool positions may occur. The cutting plane method tool and the curved surface trajectory are in the same plane, so that the processing trajectory and residual height are more evenly distributed, and the processing efficiency is higher, but it also causes the problem of tool position redundancy and lack. Although the calculation of equal residual height method is complicated, it can avoid the problems of redundancy and lack of tool position [9].

Due to the particularity of the ultrasonic vibration cutting tool, the dagger knife can only be cut according to the trajectory planned by the programmer, and the disc knife has no pulverized body, and the tool cannot cut with a large margin in the radial direction alone, otherwise the remaining material cannot be broken. In this case, the parts are pulled up and cut and scrapped. Therefore, the disc cutter needs to be processed according to the depth and width cut by the dagger cutter. The specific cutting is shown in Figure 3.

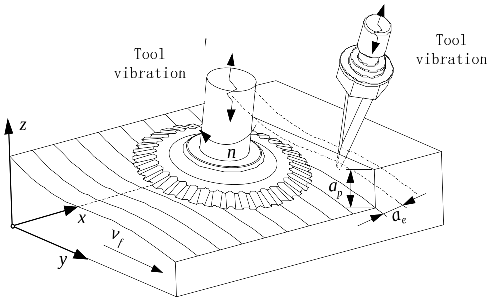

Figure 3 Schematic diagram of ultrasonic vibration cutting of honeycomb core material

It can be seen from Figure 3 that in order to realize the ultrasonic vibration cutting of honeycomb core parts, in the current coordinate system, the section method (Figure 4) is used to take the contour end surface of the honeycomb core material part as the reference plane, based on the reference plane, to move the tool As the offset value, use a set of parallel planes to intercept the surface to be machined on the fitted process surface, and intercept a series of intersections, namely the cutting trajectory lines. The number of cutting trajectories can be determined according to the size of the part and the processing of the part Accuracy and efficiency can be obtained from the cutting distance and the diameter of the disc tool. Assuming that the number of cutting tracks is Ns, the maximum distance in the length direction of the part is Ls, and the diameter of the disc tool is Ds, the number of cutting tracks of the part is:

$$N_S = \left[\frac{L_s + \frac{D_s}{2} - a_e}{a_e} \right] + 1 \tag{1}$$

In the formula, [] is the rounding symbol.

The dagger knife moves forward along the cutting trajectory, and the disc tool is offset by a distance along the trajectory cut by the dagger knife to complete the curved surface processing.

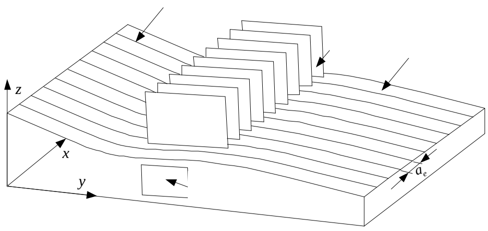

Figure 4 Sectional plane method

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4. Determination of the cutting attitude of honeycomb core material by ultrasonic vibration

With the development of aviation equipment technology, higher requirements are put forward for the performance of aviation equipment. Therefore, the honeycomb core material parts used in a large number of new military and civil aircraft are no longer a single ruled surface honeycomb, but a complex surface type. Honeycomb, such as hyperbolic convex-concave surface, rotating concave surface, blind groove semi-cylindrical surface, etc. Therefore, to realize the machining of honeycomb core composite parts, tool attitude control should be performed on the basis of cutting path generation to avoid machining interference.

4.1. Analysis of Surface Characteristics of Honeycomb Core Material Parts

In the ultrasonic vibration cutting processing of honeycomb core material parts, in order to facilitate the calculation and processing of the surface of the part, the processed surface is assumed to be a smooth surface, and the parameter expression is [10]

$$S(u,v)=\sum_{i=0}^{k}S_i(u,v)=\sum_{i=0}^{k}[u^3\quad u^2\quad u\quad 1]Q_i[v^3\quad v^2\quad v\quad 1]^T \tag{2}$$

Where Si(u,v) is the parametric equation of the i-th surface patch; 4 4-th order matrix, expressed as the vector matrix of the i-th surface patch;, is the two parameter variables of the parametric equation, and k is the number of the surface patch number. For any given point on the surface, the following three vectors can be derived:

$$\begin{cases} S_u=\dfrac{\partial S(u,v)}{\partial u} \\ S_v=\dfrac{\partial S(u,v)}{\partial v} \\ n=\dfrac{S_u\times S_v}{|S_u\times S_v|} \end{cases} \tag{3}$$

Where: the tangent vector of the surface along the parameter direction; the tangent vector of the surface along the parameter direction; the normal vector of the surface.

From the definition of normal curvature, the normal curvature of the surface can be solved

$$k_n=\frac{w^T Mw}{w^T Lw} \tag{4}$$

Where $w=\begin{bmatrix}\dot{u}\\ \dot{v}\end{bmatrix}$;Is the first differential basic form of the surface, $L=\begin{bmatrix}S_u\cdot S_u & S_u\cdot S_v\\ S_v\cdot S_u & S_v\cdot S_v\end{bmatrix}=\begin{bmatrix}A & B\\ B & C\end{bmatrix}$;

Are the second differential basic form of the surface, $M=\begin{bmatrix}S_{uu}\cdot n & S_{uv}\cdot n\\ S_{uv}\cdot n & S_{vv}\cdot n\end{bmatrix}=\begin{bmatrix}D & E\\ E & F\end{bmatrix}$,

$S_{uu}=\dfrac{\partial^2 S(u,v)}{\partial u\partial u},S_{uv}=\dfrac{\partial^2 S(u,v)}{\partial u\partial v},S_{vv}=\dfrac{\partial^2 S(u,v)}{\partial v\partial v}$ From equation (4) and let $P=CD+AF-2BE$, You can find the curvature of any point on the surface k_{max}, k_{min}.

$$k_{max}=\frac{P+\sqrt{P^2-4|L||M|}}{2|L|} \tag{5}$$

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$$k_{\min} = \frac{P - \sqrt{P^2 - 4|L||M|}}{2|L|} \tag{6}$$

The product of curvature, is the total curvature

$$K = \frac{DF - E^2}{AC - B^2} \tag{7}$$

The average value of the sum of curvature and is the average curvature

$$H = \frac{P}{2(\mathrm{AC} - \mathrm{B}^2)} \tag{8}$$

Therefore, the local shape of the surface at this point can be obtained by calculating the K and H values, as follows:

1) Hyperbolic point: $K<0$;

2) Concave parabolic point: $K = 0, \ H>0$;

3) Convex parabolic point: $K = 0, \ H<0$;

4) Convex ellipse point: $K>0, \ H<0$;

4.2. Ultrasonic Vibration Cutting Tool Posture Definition and Interference Treatment

The control of the tool posture is actually the control law and method of the tool axis direction during the cutting process of the tool, mainly to prevent local interference between the tool and the machined surface. In the ultrasonic vibration cutting of honeycomb core material parts, the dagger knife is used to rough the parts in a forward inclined manner, and the tip of the knife is sharp, and the radius of curvature tends to be infinitely small. It will not interfere with the surface of the part during processing. Therefore, This section mainly controls the cutting posture of the disc cutter.

At present, the commonly used tool axis control methods are perpendicular to the surface, parallel to the surface and inclined to the surface. For the rotary vibration cutting of honeycomb core material, the commonly used method is the control method of the tool axis inclined to the surface. The tool axis is inclined at an angle with respect to the normal vector of the part surface, and the part is cut from high to low. The schematic diagram of this kind of tool axis control method is shown in Figure 5:

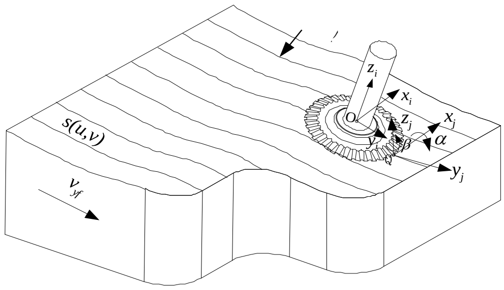

Figure 5 Schematic diagram of the attitude control of the disc cutter

In Figure 6, it is the tool's own coordinate system, which is a local coordinate system established at any point on the cutting path line. The coordinate system takes the normal vector direction of the cutting point on the processed surface as the axis and cuts at the cutting point Q. The radial cutting direction and the tool feed direction on the plane are the axis and the axis. In the local coordinate system, the cutting tool is rotated in two directions with the cutting point Q as the base point: first rotate the tool around the axis by a forward inclination angle, Then rotate the tool around the axis by a roll angle. In this way, the posture of the tool can be defined by two rotation angles.

The control of the tool posture is mainly to avoid the contact between the bottom surface of the tool and the processing surface and the interference between the cutting edge and the processing surface. In the process of cutting honeycomb core parts by the rotary vibration of the disc cutter, the size of the rake angle is closely related to the shape of the processing surface, so The interference processing of disc cutters mainly analyzes and calculates the forward inclination angle of disc cutters. The interference analysis diagram of disc cutter processing is shown in Figure 6.

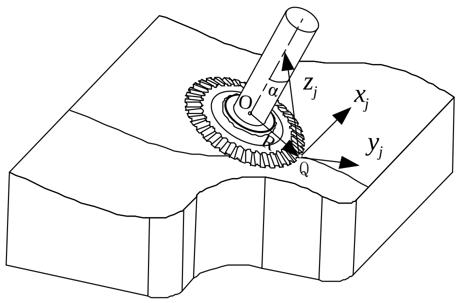

Figure 6 Schematic diagram of disc cutter interference analysis

In Figure 6, is the rake angle of the tool and the radius of the disc cutter. At the tool contact point, the effective cutting radius of the disc cutter along the feed direction is. In order to prevent interference during the cutting process, the effective cutting radius of the cutter is So there is

$$\frac{R}{\sin\alpha} \le \frac{1}{k_{\max}} \tag{9}$$

The limit value of the forward tilt angle can be obtained

$$\alpha = \arcsin(\mathrm{R} \cdot k_{\max}) \tag{10}$$

The differential geometric structure of the complex profile of the honeycomb core composite parts includes hyperbolic points, convex parabolic points, concave parabolic points and convex elliptic points. The calculation formulas for the forward inclination angle are given below in combination with the above analysis:

Hyperbolic poin: $K<0$, Forward angle $\alpha = \arcsin(\mathrm{R} \cdot k_{\max})$;

Concave parabolic point: $K = 0$, $H>0$, Forward angle $\alpha = \arcsin(\mathrm{R} \cdot k_{\max})$;

Convex parabolic point: $K = 0$, $H<0$, Forward angle $\alpha = 0$;

Convex ellipse point: $K>0$, $H<0$, Forward angle $\alpha = 0$.

Therefore, under the condition that the normal vector and the forward inclination angle of the curved surface are known, the two additional degrees of freedom of the ultrasonic vibration cutting machine tool are used to make the cutting tool rotate around the axis and the axis, and to ensure that the leading edge of the tool reaches the predetermined cutting position. Avoid processing interference.

4.3. Example of generating program for ultrasonic vibration cutting of honeycomb core material

Through the establishment of the equivalent tool, the planning of the cutting trajectory, and the control of the tool posture, the cutting trajectory of the dagger knife and the disc cutter in Fig. 7 was generated, and the generation program was verified by the VT simulation software. The verification results showed that the generated The tool path meets the accuracy requirements of the parts, the surface quality is good, and the processing efficiency is high.

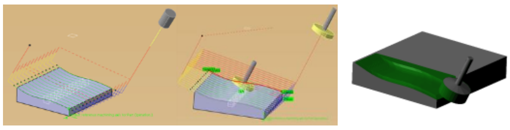

Figure 7 Example of program generation

5. Conclusion

This chapter studies the key links of NC programming technology in Nomex honeycomb core composite material ultrasonic vibration cutting technology. Based on the analysis of the existing programming software functions and tool structure, the equivalent cutting in the honeycomb core material ultrasonic vibration cutting CNC programming is established. Tool. It provides a basis for the generation of dagger tool path in programming and the interference check in the simulation of disc cutter cutting; based on the section method and the analysis of the surface characteristics of the part, the generation method of the ultrasonic vibration cutting processing path of the honeycomb core material and the tool attitude control are carried out The research has realized the generation of high-quality tool paths for ultrasonic vibration cutting of honeycomb core parts, laying the foundation for the generation of accurate, efficient and concise CNC machining programs.

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