Research on Automatic Tape Laying of Elliptical Cylinder

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Introduction

Automatic Tape Laying technology [1, 2] (ATL) is an automatic molding technology, which can manufacture the composite parts with high strength/ modulus and has remarkable advantages, such as high production efficiency, stable quality and low rate of waste relative to the filament winding technology and hand-laying. The western developed countries have researched in the automatic tape laying technology several years earlier [3-10], and now this technology has developed maturely to manufacture the aeronautic composite structures. The research on automatic tape laying technology domestic started later [11], and related researches are still in the exploration. The [12-14] mainly studied the molding technology of simple components with plane and cylinder surface, but the elliptical cylinder, as the similar structures on the aircraft, its trajectory planning and related researches are rarely reported.

Based on the above, the research on tape laying trajectory planning of elliptical cylinder is carried out. The discussions involve with the trajectory control of end cutting section, the calculation of elevating axis stroke, and the adjustment of the layer angle to the changes of layer thickness. Using MFC library and OpenGL technology, the trajectory planning and post-processing of elliptical cylinder is realized under the platform of VC + + 6.0. The simulation of tape laying process is illustrated [15], and the actual experiment verifies the correctness and validity of this algorithm.

1 Tape laying trajectory planning
1.1 Trajectory control of the end cutting section

According to the load requirements and trajectory design demands, the trajectory often uses several different laying angles in the tape laying process.

Different laying angles have the different end cutting shapes correspondingly, so the coordination-control of the equipment operation, the trajectory running and the ultrasonic cutting knife's action must be done correspondingly in the end trajectory planning.

To determine the motion quantity of the machine and ultrasonic cutting knife, the coordinates of the start and the end cutting point must be obtained. Assuming the position of the elliptical cylinder mold in Cartesian coordinate system is shown as the Fig.1 illustrated. Where w is the tape width, q is the laying angle, and (x_0, y_0, z_0) is the coordinates of P which is the end point on center trajectory of the tape. The unknown quantities are the coordinates of the starting cutting-point P_1 and ending cutting-point P_2 of the cutting knife, which can be identified by the Eq. (1), describing as (x_1, y_1, z_1) and (x_2, y_2, z_2) respectively.

$$\begin{cases} x_0 = x_1 = x_2 \\ (y - y_0)^2 + (z - z_0)^2 = (\dfrac{w}{2\sin q})^2 \\ \dfrac{y_0{}^2}{a^2} + \dfrac{z_0{}^2}{b^2} = 1 \end{cases} \qquad (1)$$
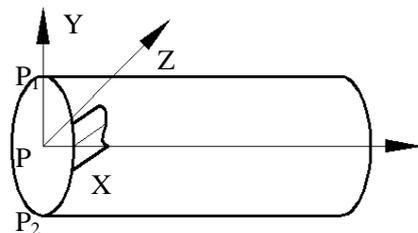

Fig.1 The end laying of elliptical cylinder
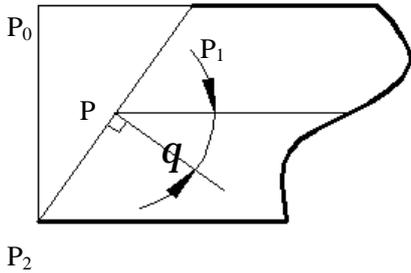
Fig.2 The end motion quantity

have all be identified. The relation between the motion distance of machine trajectory and the motion quantity of the cutting knife is shown as the Fig.2 illustrated, where $\overline{P_0P_1}$ and $\overline{P_2P_0}$ are the motion quantities of the machine and the cutting knife respectively, which can be solved by the Eq. (2). In the Eq. (2), the positive and negative of the laying angle q will determine the cutting direction, and $\left|P_0P_1\right|$ and $\left|P_2P_0\right|$ are the magnitude of the quantity motion respectively.

The trajectory planning of machine's cutting motion will be carried on when the laying angle, the starting cutting-point and the ending cutting-point

$$\begin{cases}\left|P_0P_1\right| = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2 + (z_1 - z_2)^2} \bullet \cos q \\ \left|P_2P_0\right| = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2 + (z_1 - z_2)^2} \bullet \sin q\end{cases} \qquad (2)$$

1.2 The stroke calculation of elevating axis

In the tape laying process, the pressure roller must be still in the normal direction acting vertically on the surface mold to guarantee the good stretch of the tape, as the Fig.3 illustrated. But after the axial rotation of elliptical cylinder, the position of the normal vector of the pressure roller will change, and the stroke of the elevating axis needs to be adjusted to meet the requirement of vertical interaction.
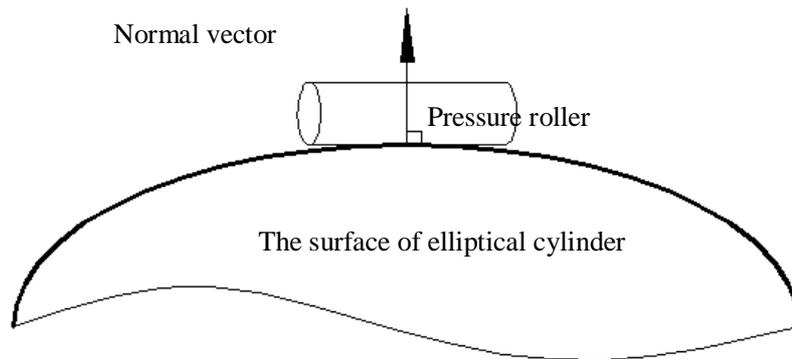

Fig.3 The pressure roller vertically interacts with the normal vector of the mold.

Now only ellipse issue in plane yz will be considered, and the position of the ellipse in the coordinate system is shown as the Fig.4 illustrated.

The normal line of some point on ellipse in yz rectangular coordinate system can be described in Eq. (3).

$$z - z_0 = \frac{a^2 z_0}{b y_0}(y - y_0) \qquad (3)$$

Assuming the mold rotates the angel q, which will be equivalent to the yz coordinate system converts into the $y'z'$ coordinate system, and the
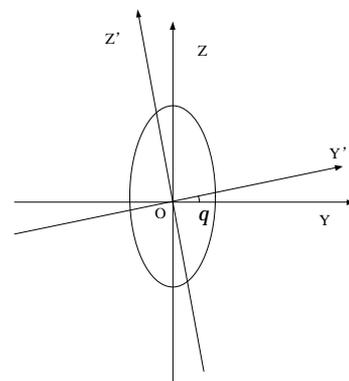
conversion formula is shown is Eq. (4).

Fig.4 The rotation of mold

$$\begin{cases} y' = y\cos q + z\sin q \\ z' = -y\sin q + z\cos q \end{cases} \quad (4)$$

$$k = (\sin q + \frac{a^2\cos q(-y_0\sin q + z_0\cos q)}{b^2(y_0\cos q + z_0\sin q)}) / (\cos q - \frac{a^2\sin q(-y_0\sin q + z_0\cos q)}{b^2(y_0\cos q + z_0\sin q)}) \quad (5)$$

Because of the requirement that the pressure roller must be vertical to the normal vector of the mold, which is equivalent to the normal vector of (y_0, z_0) is parallel to y', then $k = 0$ is in conclusion. At the same time, the point is always on the ellipse, as the Eq. (6) shown.

$$\frac{y_0^2}{a^2} + \frac{z_0^2}{b^2} = 1 \quad (6)$$

Then relationship between the point (y_0, z_0) and q can be solved from the Eq. (5) and Eq. (6), and z_0 is the stroke of the elevating axis.

1.3 The adjustment of the layer angle to the change of layer thickness

Taking the y' and z' into Eq. (3), and the slope of normal line will be obtained in the Eq. (5).

Generally, the composites are manufactured by several layers with different layer angles, and the gaps between adjacent tapes will become larger and larger with the increase of the layers' thickness. Aiming at this problem, an algorithm of adjustment of the layer angle to the changes of layer thickness is brought forward to ensure the gaps maintain a minimum and improve the quality of the product eventually.

Due to the rarely perimeter calculation formula of ellipse, the Xiang Mingda formula is taken here as the Eq. (7) show.

$$L = 2pa\left[1 - \left(\frac{1}{2}\right)^2 e^2 - \left(\frac{1\cdot3}{2\cdot4}\right)^2\frac{e^4}{3} - \left(\frac{1\cdot3\cdot5}{2\cdot4\cdot6}\right)\frac{e^6}{5} - \left(\frac{1\cdot3\cdot5\cdot7}{2\cdot4\cdot6\cdot8}\right)\frac{e^8}{7} - \mathbf{L}\right] \quad (7)$$

Where $e = \sqrt{1 - \frac{b^2}{a^2}}$.

With the increase of the thickness, a is increase, and the calculation formula is: $a = a + nt$, (where t is the tape width, n is the amount of layers, $n = 0, 1, 2, 3\mathbf{L}$). So $L = f(n)$, and the perimeter of ellipse is changes with the parameter n.

Assuming the layer angle is q, and the width of tape is w, so the actual layer angel q' can be calculated when the thickness of layers is changed using the Eq. (8).

$$q' = \arcsin\left(\frac{w}{f(n) / \left[\frac{f(n)}{w/\sin q}\right]}\right) \quad (8)$$

Where $[\ ]$ is the symbol of taking the integer part.

2 Simulation and experiment

With the platform of VC++6.0, the program is programmed according to the following flow, as shown in Fig.6. The three algorithms and the laying

process are simulated using the MFC and OpenGL technology. The simulation results show that above algorithms have a rational trajectory planning effect, a shipshape end cutting, high precision control of axis motion, good spreadability and so on, as the Fig.6 illustrated.
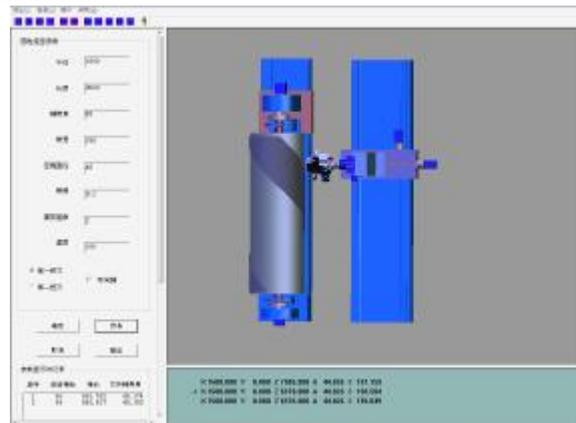

Fig.6 The simulation interface of automatic tape laying

The machine control codes generated by this algorithm are used into the actual experiments. The results show that the simulation is in good agreement with the actual experiment, as the Fig.6 illustrated.

The effect of this algorithm makes the tapes have a shipshape end cutting, the pressure roller act on the mold surface in the normal vector direction, and the tapes have a good integral spreadability.
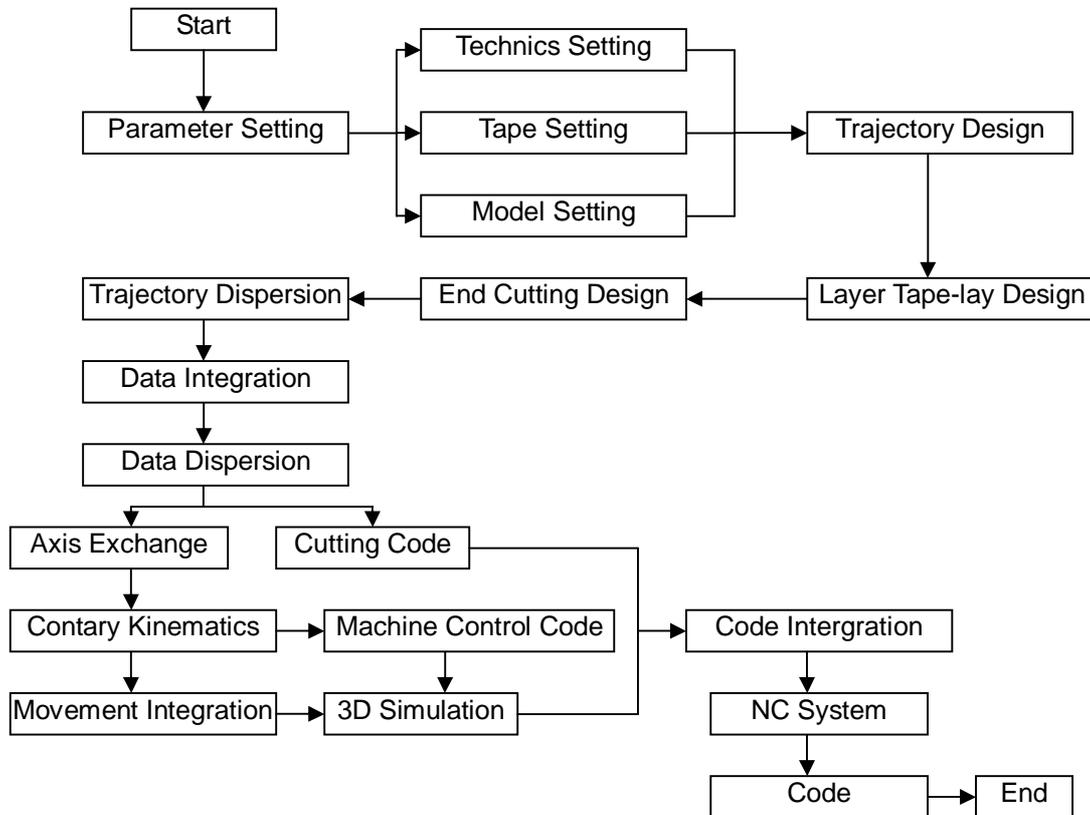

Fig.5 Pragram Flow

Fig.6 The actual experiment process

3 Conclusions

Based on the several key issues in the trajectory planning of elliptical cylinder of the automatic tape laying technology, the relative algorithms such as the trajectory control of end cutting section, the calculation of elevating axis stroke, and the adjustment of the layer angle to the changes of layer thickness have been raised and the software realization and simulation have been implementation. The simulation shows the tape laying process dynamically and the good effects. Finally, the NC codes of machine have been obtained based on the simulation trajectories, and the actual experiments have been carried out. The results show that the actual tape laying effects meet the design requirements and the correctness/ feasibility of the relative trajectory planning algorithms of elliptical cylinder.

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