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Optimization Design and Research on Macro Program of Archimedes Spiral Machining

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Abstract. By analyzing the characteristics of Archimedes spiral equation, this equation takes the included angle as the variable, and the algorithm of equal included angle straight line approximation can be used to calculate the interpolation points. Using the advantage of parametric programming by FANUC system macro program, a G instruction（G102） is customized to realize the machining of Archimedes spiral surface. This G instruction is used in the same way as the system's inherent G code, similar to a custom fixed loop code. It is different from the program number that G code must indicate when calling macro program. The G102 code can complete the machining of Archimedean spiral surface only by assigning values to each letter according to the format specified in the text. After processing verification on GLU28x40 CNC, the use method of customized G code is as flexible and convenient as the fixed cycle G code provided by CNC. It can process Archimedes spiral profile that meets the requirements, and use the equal angle straight line approximation algorithm for interpolation. The calculation speed is fast, which effectively improves the processing efficiency of the profile.

Keywords. Archimedes spiral, macro program, custom G code, interpolation.

1. Introduction

With the widespread application of CNC, the machining of non-circular curves has become more and more common. Among the various non-circular curves used in industry, the Archimedes spiral is widely used because of its function of saving materials and energy consumption. In mechanical transmission, it is often necessary to convert rotary motion into linear motion. The cam device not only pushes the driven rod to perform periodic mechanical movements such as reciprocating linear motion and swing through the rotation of the cam around the fixed axis, when the motion of the driven rod is proportional to the diameter When decreasing or increasing, the driving part cam is required to be controlled by the Archimedes spiral . In addition, the machining of profile milling cutters and gear hob shoveling also needs to be controlled with the Archimedes helical profile. The Archimedes spiral profile is widely used at

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home and abroad. In order to reduce the dependence on mineral fuels, the Archimedes spiral profile is used to improve the wind turbine in the new horizontal axis wind turbine designed by wind energy. performance [1]; by optimizing the Archimedes spiral profile to solve the free-form surface turning tool path and improve the processing efficiency [2]; using the equidistant Archimedes

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spiral fitting method to realize the high precision of the spiral profile Efficient processing[3], combining the double-layer torus structure with the Archimedes slit structure, a metasurface structure with a double-layer Archimedes spiral distribution that can be used to excite SPP vortex light[4] . The above literatures mainly study the use of Archimedes spirals and their profiles, and some literatures have also studied the machining methods of Archimedes spirals, but they are mostly presented in the form of macro program calls [5- 7].

By analyzing the characteristics of Archimedes' spiral equation with the included angle as the parameter, using the equal angle straight line approximation algorithm, combined with the advantages of the FANUC system for parameterized programming, a G code is customized. The usage method of this G code is the same as the inherent G code of the system, which is equivalent to a self-defined fixed cycle code. It is different from the G code calling macro program which must specify the calling program number. The meaning of the letter address and the assignment of each letter can complete the processing of the Archimedes spiral surface, which brings great convenience to the programmers who do not have the knowledge of macro programs to process the Archimedes spiral surface. The custom G code has been verified on the GLU28X40 gantry machining center. The custom G code is as flexible and convenient as the canned cycle code (such as G81) that comes with the CNC machine tool, which effectively improves the efficiency of the profile machining and reduces programming. programming burden on personnel.

2. Archimedes spiral

2.1. Definition of Archimedes' spiral

Archimedes' spiral is also called "constant velocity spiral". Spiral refers to a curve that rotates around some fixed points or axes and expands or contracts continuously. Archimedes' spiral is a kind of two-dimensional spiral. In on spiral, Archimedes' spiral is defined as follows: when point P moves along the moving ray OP at constant velocity, the ray rotates around point o at equal angle. Then the trajectory of point P is called Archimedes spiral, and its polar coordinate equation is $r=a\theta$。 The distance of each arm of the helix is always $2\pi a$. Its shape is shown in figure 1.

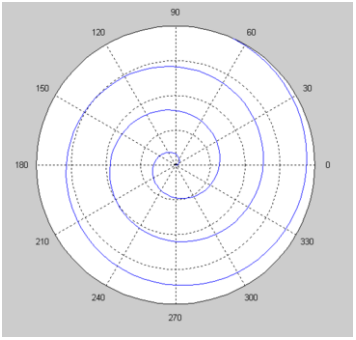

Figure 1. Archimedes spiral

2.2. Archimedes' Spiral Equation

In mathematics, the polar coordinate system is a two-dimensional coordinate system. The points in the coordinate system are represented by an included angle and a distance from the center point to the pole. The standard polar coordinate equation of Archimedes' spiral is as follows:

$$r(\theta) = a + b(\theta) \tag{1}$$

In formula (1):

b- Archimedes' spiral coefficient, in mm/°, indicating the decrease (or increase) of the polar radius for each rotation of 1°;

θ- Polar angle, in degrees, represents the total rotation angle of Archimedes' spiral;

a- When θ= Polar radius at 0°, in mm.

Changing the parameter a will change the shape of the helix, and B controls the distance between the helices, which is usually a constant.

In the plane rectangular coordinate system, the formula from polar coordinate system to rectangular coordinate is:

$$\begin{cases} x = r\cos\theta \\ y = r\sin\theta \end{cases} \tag{2}$$

2.3. Archimedes Spiral Interpolation Algorithm

In the numerical control system, in order to realize the machining of non-circular curves, the non-circular curves are usually approximated by linear interpolation and circular interpolation [8-10]. Based on the Archimedes spiral equation, the included angle is taken as the parameter, so the equal included angle linear approximation algorithm is preferred to calculate the interpolation points, as shown in figure 2. According to formula (2), X_i and Y_i are obtained to obtain a series of points.

approximation method:

The specific steps are as follows:

1) Determine the allowable step size, and make the

2) Let Archimedes' spiral parameter equation be formula (2);

3) Calculate the polar angle from the given equal clamping degree, which will be brought into formula (2) to find a series of points (x_i, y_i);

4) Then point (x_i, y_i) is the endpoint coordinate of each approaching line segment;

5) Repeat steps 3) and 4) to finish paper interpolation.

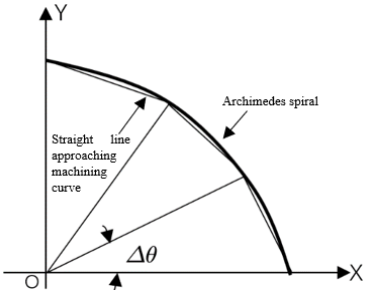

Figure 2. Schematic diagram of isometric straight line segment

3. Definition of Archimedes Spiral G Code

In the FANUC slave system, the system parameters must be set before defining the G code to ensure that the G code is effectively used. Set the G code to call the macro program in the system parameters, which is the same as the method to call the (G65) macro program in modeless mode.

3.1. System Parameter Setting

When editing subroutines, try to use 8000 or 9000 series program numbers. They can be edited / deleted by 3202#0 and 3202#4 respectively. The 9000 series number is used in this programming. The system parameter no.3202#4 can lock the program through No.3219 (PASSWD) and parameter No.3211 (KEYWD) to protect the program No.9000- No.9999 In the locked state, unless the correct password is entered, the 9000 series number cannot be modified, realizing the effective protection of the programmed. The parameter setting requirements and their meanings are shown in table 1.

Table 1. Parameter setting of Archimedes spiral G code and its significance

Parameter setting	significance
No.6001#6=0	No.6001#6: Whether the public macro variable #100-#149 is cleared after reset: 0- cleared after reset; 1-reset does not clear
No.3202#4=0	No.3202#4: Whether macro programming is prohibited: 0-allowed; 1- prohibition
No.6040=0	When set to 0, it is forbidden to automatically specify the calling relationship of multiple G codes and macro programs.
No.6043=0	When set to 0, it is forbidden to automatically specify the calling relationship between multiple G codes with decimal points and macro programs
No.6050=102	No.6050-No.6059 Call macro program 9010-9019 with G code, parameter number(No.6050-No.6059) and the program number (O9010-O9019) correspond to each other in sequence

3.2. Archimedes Spiral Macro Program Design

In FANUC system, the codes after G100 can be used to customize the G code macro program. This paper specifies to write 102 in NO.6050, and use G102 code to call Archimedes' spiral macro program O9010 (as shown in figure 3), and design according to the spiral formula to form a design flow chart.

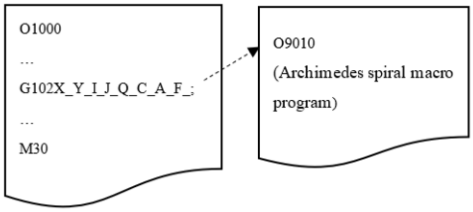

Figure 3. G102 code calls Archimedes spiral macro program

3.2.1. G102 Design Flow Chart

According to the Archimedes' spiral equation formula (2), the interpolation points are calculated by using the equal angle straight line approximation algorithm, and the general format of G102 is set to G102 X_ Y_ I_ J_ Q_ C_ A_ F_; The address of the letter is its general meaning, and the parameter is used to specify type I, corresponding to the letters used (X、Y、I、J、Q、C、A and F respectively)The macro program O9010 needs to initialize the local variable#24、#25、#4、#5、#1、#17、#3、#1 and#9 for calling. The specified G102 code is the code that calls the specified Archimedes spiral macro program. The main program statement of the macro program is as follows:

G102 X_Y_I_J_Q_C_A_F_ ;

Of which:

X_ Y_: Specifies the coordinate value of the endpoint of the Archimedes spiral. When relative programming is used in the main program, the relative coordinate value setting is used; when absolute programming is used in the main program, the absolute coordinate value setting is used.

I_ J_: Specifies the coordinates of the center point of the Archimedes spiral, which is set as the distance (with symbols) from the starting point of X (Y) to the center point of the spiral.

Q_: Specifies the polar radius increment per revolution of the Archimedes spiral.

C_: Specifies the number of revolutions from the beginning of the Archimedes spiral to the end of the spiral, which is equal to the total rotation angle of the spiral /360.

A_: Specifies the Archimedean spiral interpolation point step (angle value, for example, set to 1 at 1°).

F_: Feed speed, which is the maximum possible value. The actual feed speed depends on the arc length step of the helix (influencing factors: angular distance, polar radius) and the set value of motor acceleration and deceleration parameters.

The flow chart of Archimedes spiral macro program design is shown in figure 4.

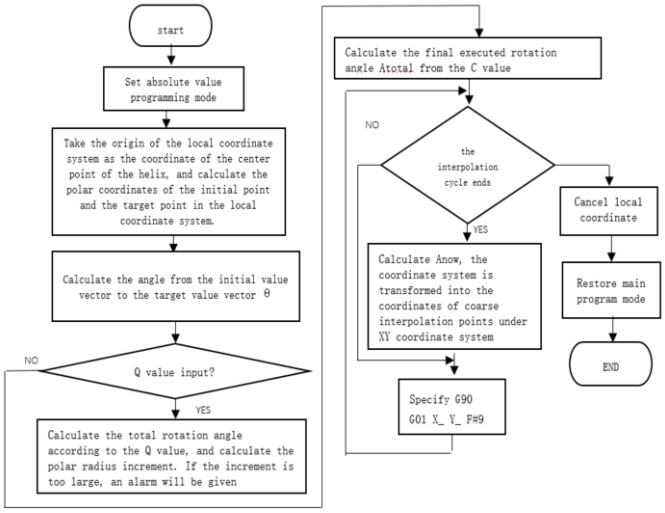

Figure 4. Archimedes spiral processing flow chart

According to the parameter setting rules of FANUC-0i system, the Archimedes spiral macro program is compiled in combination with the macro program design flow chart.

3.2.2. Precautions for Calling G102 Instruction

In order to correctly use G102 during machining, the following matters shall be paid attention to during calling:

1) Attention must be paid to the input of decimal point in the assignment;

2) Only one of the Q and C values can be specified. When Q and C values are specified at the same time, only the Q value shall prevail;

3) When specifying Q and C values, be sure to input accurate values. If the entered values conflict with the start and end values, the system will alarm 3000 (para error);

4) The relationship between the feed speed and the angle step is contradictory. Setting a smaller feed step will lead to a smaller feed speed. Please set the value a appropriately (refer to part 3 of the manual).

5) The feed speed f only sets the value that the axis reaches the command speed. The feed time between steps may not make the axis reach the command speed, so the actual speed will be smaller than the feed speed.

3.2.3. Scope and Limitations of G102 Directive

The Archimedes spiral G102 code has a wide range of applications, and the starting point and ending point of the spiral can be arbitrarily selected. However, the following principles shall be followed during use:

1) The rotation direction of the helix is fixed to the counterclockwise direction;

2) When using, be sure to input the correct number of spiral coils or spiral pole diameter increment;

3) Radius of terminal pole cannot be 0;

4) Only applicable to helix machining in XY plane;

5) The running speed of the program depends on the acceleration and deceleration performance of the motor.

3.2.4. Step Angle, Helix Curve Characteristics and Feed Time of G102 Command

During Archimedes spiral interpolation, the equal angle straight line approximation algorithm is used for processing. In order to obtain the best processing effect, repeated experiments and demonstrations show that (as shown in figure 5) when the polar radius changes from 0 to 50mm, the spiral contour characteristics and feed time when different angle steps are set (ignoring the influence of motor parameter setting). The curve properties are described as follows:

Obtain the contour of one circle of machining (the polar radius increment is 10mm), and obtain the E value shown in figure 5 to represent the shape characteristics of the curve (refer to the Archimedes spiral curve obtained when the angular step $\Delta\theta$ is 0.5 °. The curve shape characteristics (see table 2) and feed time (see table 3) are shown.

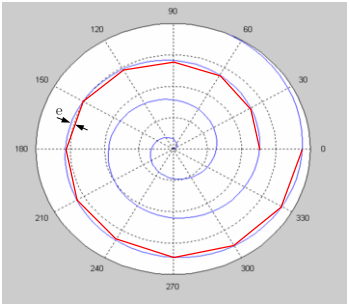

Figure 5. Helix curve properties

Table 2. Curve shape characteristics: (um)

Start polar radius - end polar radius	Angular step1°	Angular step5°	Angular step 10°
0-10	ignore	5	20
10-20	ignore	15	55
20-30	ignore	25	100
30-40	2	35	130
40-50	2	45	180

Table 3. Feed time: (msec)

Start polar radius - end polar radius	Angular step1°	Angular step5°	Angular step 10°
0-10	38000	13500	8750
10-20	55100	17200	10800
20-30	62500	19200	12300
30-40	67100	20900	13600
40-50	70600	23500	15000

4. Conclusion

Based on fanc-0i system, combined with the characteristics of Archimedes' spiral equation, which takes angle as parameter and adopts equal included angle straight line approximation algorithm for interpolation, and taking advantage of FANUC system's parametric programming, a G code (G102) is customized. Each parameter is assigned according to the requirements through the specified format to realize the machining of Archimedes' spiral surface.

The verification on the glu28x40 gantry machining center shows that:

-The customized G102 is as flexible and efficient as the fixed cycle G code (such as G73, G81, G87 etc.) of the CNC; So that operators who do not use CAM software programming can also process Archimedes spiral surface.

-The Archimedes spiral profile that meets the requirements can be machined by assigning values according to the format specified in G102, and the machining efficiency of the profile can be improved by about 10%.

-Using the equal angle straight line approximation algorithm to calculate the interpolation points, the operation speed is 5% higher than that using CAM software g01/g02 for fitting programming;

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