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Speed Planning and Imputation Technology Development of CNC System

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Abstract: In order to better carry out the research of the integrated design of the speed planning of CNC system, it is necessary to systematically understand and learn the existing representative work. The methods and technical progress of speed planning and insertion in CNC machining, including S curve planning algorithm, trapezoidal planning algorithm, parameter curve speed control algorithm, NURBS curve fitting algorithm and adaptive insertion algorithm. The existing methods have the contradiction between machining accuracy and efficiency, and the calculation amount required for the accurate prediction of the deceleration point of speed planning is still large. With the rapid development of technologies such as artificial intelligence and machine learning, intelligent algorithms can gradually improve the effect of speed planning through learning and optimization, and make adaptive adjustment according to the real-time feedback in the processing process, which will further improve the processing efficiency and precision.

1. Preface

CNC machine tool refers to an advanced mechanical equipment that controls the working action and processing process of the machine tool through preprogramming. Compared with the traditional machine tool, it has the characteristics of high speed, high efficiency, high precision, high automation degree and other characteristics, widely used in aerospace, aviation, automotive, electronics, mold and other manufacturing fields. CNC machine tool adopts computer control, can realize automatic processing through programming in advance, greatly improve the production efficiency and product quality. The control system of CNC machine tool is composed of two parts: software and hardware. The hardware part includes sensors, servo drive system, CNC device, etc.; the software part includes programming, processing parameter setting, data processing and other functions. With the development of artificial intelligence, the Internet of things, cloud computing and other technologies, CNC machine tools have been updated, showing a development trend of intelligence, networking and information.

With the rapid development of CNC machine tools, people put forward higher requirements for the accuracy and efficiency in the actual CNC machining, and the core content of the machine machining process is the speed planning. It is always hoped that the tool can cut along the tool path faster under the premise of satisfying the kinematic constraints and geometric error constraints, so as to improve the machining efficiency. Therefore, the speed planning and insertion technology of the CNC machine tools determine the quality and efficiency of the machining workpiece, which plays a vital role in the CNC machining.

2. Speed planning

CNC machine tool speed planning is to control the speed and position of the tool or workpiece in the machining process by controlling the servo motor in the CNC system. The purpose of speed planning is to improve the machining accuracy and machining efficiency. In CNC machine tools, speed planning mainly includes acceleration planning, deceleration planning, constant motion planning, etc.:

(1) Acceleration planning is mainly to make the processing process of the tool or workpiece in the initial state to reach the set speed of the time as short as possible, but also to avoid excessive acceleration caused by machine vibration and processing quality decline. Generally speaking, the acceleration planning will be planned using the "S curve" or "trapezoidal curve".

(2) Acceleration planning is mainly designed to smoothly stop the tool or workpiece at the end of the machining process, to avoid the sudden reduction of speed caused by machine vibration and processing quality decline. Reducation planning will also use "S curve" or "trapezoidal curve" planning.

(3) The uniform speed motion planning is mainly to maintain a certain speed and position in the processing process, making the processing quality more stable and accurate. Uniinciate motion planning generally adopts linear planning or arc planning.

In addition, there are complex curve planning, acceleration, deceleration and constant speed combination planning and other methods, which can be selected according to the processing technology and requirements. In short, speed planning is a very important part of the CNC machine tools, through a reasonable planning method can improve the processing efficiency and processing accuracy, to ensure the processing quality.

2.1 Traditional speed planning algorithm

Traditional speed planning algorithm include S curve planning algorithm, trapezoidal planning algorithm and so on. These algorithms all use simple mathematical models to model the processing path, and design an appropriate speed planning scheme according to the processing process requirements and the performance characteristics of the machine tool. Among them, the S curve planning algorithm is the most commonly used algorithm. The basic idea is to divide the processing path into acceleration section, uniform section and deceleration section, and then design the appropriate S curve acceleration planning scheme by requiring the continuity and smoothness of acceleration, so as to realize the smooth movement in the processing process. The trapezoidal planning algorithm limits the acceleration to a fixed value range to achieve smooth motion during processing. These traditional speed planning algorithms have been widely used in the processing process, and have formed a mature theoretical system.

Shi[1]summarized the 8 possible S-curve acceleration and deceleration modes that may appear in the planning. This method has good speed smoothness and high motion accuracy, but the algorithm is complicated. Luo[2]proposes a new speed planning algorithm, so that the acceleration and deceleration can change linearly on certain slope to reduce the flexible impact, but the calculation process of this method is also complicated. In terms of trapezoidal speed planning, Zheng[3]proposed a real-time interpolation algorithm based on the traditional trapezoidal acceleration and deceleration algorithm to generate the feed speed and its corresponding change interpolation cycle. The algorithm is simple and suitable for the middle and low grade numerical control system, but with large error.

2.2 Optimization algorithm for speed planning

Based on the existing research basis, domestic and foreign scholars have proposed more optimization algorithms. Len[4] proposed a three polynomial type micro high speed processing speed planning algorithm, the algorithm can realize into the speed of high speed cohesion and high speed processing deceleration distance prediction in advance, but the method will cause the frequent vibration of the machine tool, thus reduce efficiency. Wang[5]put forward a four polynomial in high quality processing polynomial speed planning algorithm research, the algorithm can realize the servo shaft smooth, flexible acceleration and deceleration control, suitable for high quality processing. However, this method can only be achieved theoretically, and it is difficult to apply in practice. Xiao[6] proposed a speed planning algorithm with exponential acceleration and deceleration speed model to plan the feed speed when starting or stopping according to the exponential law. The speed smoothness obtained by this algorithm is good, but the calculation amount is large, and the acceleration will still change, which will affect the service life of the machine tool. Dong [7] established a first-order error model to analyze the impact of the dynamic performance mismatch of each axis, and generated new feed speed constraints through this model, and realized the control of contour error by means to improve the feed speed curve.

2.3 Prospective algorithm for speed planning

In the speed planning foresight section, domestic and foreign scholars have also achieved remarkable research results. Wang[8]proposed a " S-type acceleration and deceleration method applied to the adaptive forward algorithm, which achieves high speed and smooth feed speed, but does not take into account the detailed steps of the complete classification model and calculation speed of the S-type curve in the forward control, and does not consider the impact of acceleration on the machine tool. Based on this algorithm, Dong[9]proposed a general forward-looking speed planning algorithm, which completed the dynamic optimization of the feed speed through the pre-reading of the processing program, but did not demonstrate the influence of the planning element size on the processing rate and stationarity. Yuan[10]proposed an adaptive forward-looking interpolation algorithm based on Cardinal spline curve, which can realize the high-speed connection between micro-segments. However, the essence of this method is still a continuous multi-segment forward-looking algorithm, which has certain limitations.

2.4 Parametric curve speed control algorithm

In recent years, with the development of CNC system, the parameter curve speed control algorithm emerged. Compared to the conventional rectilinear arc interpolation, Direct parameter tric of parameter parameter technique is not only small transport volume. And the processing trajectory is much closer to the design outline. S. Nam[11]presented a real-time forward-looking speed control algorithm for parametric curves. By the prospective control, he effectively ensures the flexibility of the acceleration and deceleration process. But the persistent constraints on speed are not considered enough. Ju[12]proposed the S-type feed speed optimal planning algorithm of the parameterized path, by introducing velocity, acceleration, and urgency boundary constraints into speed planning to improve the processing efficiency. However, the algorithm has too many constraints, which will limit the maximum performance of the machine tool to some extent.

3. Interpolation

The CNC machine tool refers to calculate the insertion track of each axis according to the given machining track in the CNC program, and generate the corresponding control signal according to the machining requirements to control the CNC machine tool to execute the machining action. CNC machine tool generally includes circular arc interpolation, straight line and arbitrary curve interpolation. Linear interpolation refers to direct linear interpolation between two points, arc interpolation refers to arc interpolation through multiple interpolation points, and arbitrary curve interpolation refers to interpolation on the curve calculated according to the mathematical model. The insertion of CNC machine tools is generally realized by the CNC system. In the process of interpolation, the CNC system needs to be optimized according to the processing requirements and the dynamic characteristics of the machine tool to improve the machining accuracy and efficiency. Commonly used optimization methods include speed planning, acceleration and deceleration control, predictive control and so on. At the same time, the CNC system also needs to adjust and correct the insertion process according to the real-time feedback information in the processing process, so as to ensure the processing quality and stability.

3.1 Traditional interpolation method

The traditional interpolation methods of CNC machine tools mainly include straight line interpolation and circular arc insertion.

3.1.1 Line insertion

Line interpolation is a linear interpolation motion between two points, which can be inserted along the positive or negative direction of each axis. Linear insertion is mainly used for linear processing, such as plane milling, drilling, etc. Linear interpolation can be divided into point by point comparison method and digital integration method (DDA). Point-by-point comparison method is the curve into several control points, and then each control point and the current position of the difference, according to the size of the difference and direction of speed planning and insertion control, point-by-point comparison method has the advantages of high precision, simple calculation, but in the case of larger curve change, easy to produce oscillation or shock phenomenon. Based on traditional point-by-point comparison, two axes can significantly improve the machining efficiency. The basic idea of digital integration is to decompose the curve into several segments and then calculate the acceleration, velocity and displacement of each segment respectively. The advantages of this method are its simple calculation, high accuracy and fast calculation speed[13]. Guo[14]proposed a new digital integration algorithm, which can make the x-axis and y-axis pulse distribution evenly, and control the error at 0.5 pulse equivalent on the basis of improving the efficiency.

3.1.2 Arc insertion

Arc interpolation refers to the interpolation motion on the arc that can be interpolated along the tangent direction of the arc. Arc insertion needs to be optimized according to the processing requirements and the dynamic characteristics of the machine tool to improve the processing accuracy and efficiency. The commonly used optimization methods include speed planning, acceleration and deceleration control, predictive control, etc. Kong[15]proposed a time segmentation and interpolation algorithm based on circular arc interpolation, which can interpolate again at the adjacent interpolation points and improve the machining accuracy.

3.2 NURBS curve fitting insertion algorithm

The method of fitting curve is a method of fitting small curve segment. However, most of the fitting curve interpolation calculates the interpolation parameters by high power equation, which is too complicated. Yeh[16] proposed an online fitting of NURBS curves by using continuous small curve segments. The method fits curves by least square method. If fitting succeeds, the fitting curves will be interpolated; if fitting fails, the fitting curves will be automatically processed by straight line or arc curve fitting method, which will cause large errors. Lin [17] uses straight line and circular arc code to segment curves to ensure the accuracy, smoothness and boundary conditions of each tiny connection point, and can improve the accuracy of NURBS curve fitting by inserting nodes. A tool path optimization method based on NURBS curve fitting was proposed by Zhao[18]. In this method, the smooth continuous linear segment chain of the geometry of the tool path is analyzed, and the NURBS curve fitting based on the least squares method is optimized to restore the continuity of the tool path.

3.3 Adaptive interpolation algorithm

Adaptive interpolation refers to the automatic adjustment of interpolation parameters and trajectory according to the dynamic response capacity and processing requirements of the machine tool to achieve the best machining effect. This insertion method can automatically adapt to different work shapes and processing conditions, improve the quality and efficiency of processing.

Heng[19]used the S-shaped velocity profile to segment the curve, and based on the forward algorithm.Li[20]optimized the above two methods respectively, introduced the particle velocity, and simplified the S-shaped velocity profile, thus realizing a real-time speed planning based on the uniaxial performance limit.

For real-time speed planning, some scholars have adopted different ideas: Wang[21]proposed a method to complete the speed planning in non-real-time cycles. This method is to preprocess the curve and divide each interpolation point in the speed planning process, so as to obtain a smoother speed curve. Lee[22]introduces bow height error, centripetal acceleration and acceleration constraints to judge the key points on the curve trajectory, divides the curve into several small line segments according to the key points, and finally plans the feed speed according to the limit of speed change.

4. Conclusion

The speed planning and interpolation technology of CNC system is an important part of CNC technology, which is closely related to the machining accuracy, efficiency and quality of CNC machine tools, and is also an important symbol of the automation degree of CNC machine tools. With the development of modern manufacturing industry, the processing requirements for high precision, high quality and high efficiency are constantly improving. Therefore, the development of high precision, high quality, high efficiency of speed planning insertion technology has become an inevitable trend of the development of CNC technology.

In addition, with the development of artificial intelligence, cloud computing and other technologies, the CNC system will continue to develop to the direction of intelligent, efficient, flexible and networked. In such a development background, the continuous innovation and optimization of speed planning insertion technology will help the CNC system to better meet the market demand, improve the production efficiency and machining accuracy of CNC machine tools, and promote the development and application of CNC technology.

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