A Research on NC Machining Cutting Parameters Optimization

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Abstract. This paper presents an effective method of NC machining cutting parameters optimization. For a given machine NC code, we use the secondary development tools provided by VERICUT software, the time series segmentation algorithm of sliding window technique, back stepping method for getting the feed rate based on the empirical formula and other methods to extract, process and optimize the cutting data. As a result of these, we can make the output power of the spindle reaching smooth and get the optimized processing code finally.

Introduction

It is very meaningful to keep the output power of the machine tool spindle relatively smooth in a CNC machining process. If the output power of the machine tool spindle is too low, it will affect the cutting efficiency of the machine seriously. While the output power of machine tool spindle is too high, it may cause the vibration of the machine and then affect the smooth of the machine and the tool seriously. Eventually it will seriously affect the quality of the parts being processed. As a result, the curve of the spindle output power can be ensured smooth to the fullest extent by real-time adjustment and optimization of the feed rate in a CNC machining process, with the geometry tool path unchanged. Then we can improve the economic benefit and the safety of machine, tool and work piece in the NC machining.

Generally speaking, machine parameters are selected traditionally based on some empirical data in factories with some necessary calculations. But the acquired data are generally not the optimal results due to the objective conditions [4]. Now with the development of the computer aided technology, establishing a machine parameter optimization model and then using certain optimization algorithm for parameter optimization is a more practical method for seeking the optimal cutting parameters.

In this paper, we use cutting feed rate as the optimization variables to establish an optimization model goaled at making the machine output power relatively smooth in the CNC machining. The optimization steps are as follows: Firstly, for a given machine NC code, on the Visual Studio development platform, we use the secondary development tools provided by VERICUT software—Optipath API (optimize path - application programming interface) to obtain width and depth of cut, spindle speed, feed rate and other cutting data of a CNC machining process. Besides, we use the empirical formula of cutting force to get the output value in CNC machining process and adopt the time series segmentation algorithm of sliding window technique (Sliding Window, SW) for cutting power value segmentation process at the same time. At last, we take the back stepping method to optimize the feed rate in a cutting process based on the division of the power. As a result of these, we can make the output power of the spindle reaching smooth and get the optimized processing code finally.

The optimization model of cutting parameters

Optimization variables

When the parameters of work piece, tool, and machine are determined, the main factors that affect the productivity are width and depth of cut, spindle speed and feed rate [6]. If the tool path is determined with the machining code been written, part of cutting data (such as depth and width of cut, spindle speed and feed rate) can be also determined. While modifying the NC program, this paper focuses on the optimization of the cutting feed rate v_f in order not to cause any collision and change of tool path.

Optimization goal

In this paper, simulation machining software VERICUT is used to acquire cutting data (spindle speed, feed rate, width and depth of cut) of real-time processing in the CNC machining process. The real-time processing of output power $P(t)=[n, v_f, a_w, a_p]$ is calculated by empirical formula and the cutting speed is optimized with all the cutting power data as a statistical sample. We can make the output power $P(t)$ as close to the target value P_0, which is to ensure the optimized spindle power output steadily in processing.

Constraints

The output power of the spindle is limited by feed rate, cutting torque, the amount of feed engagement, feed force, the spindle speed of selected machine tool and other factors. As the optimization target is the feed rate in this paper, it should be in the range of the minimum and maximum feed rate which the machine allows. That is,

$$v_{nim} \le v_f \le v_{\max} \qquad (1)$$

Where v_f is the feed rate, v_{nim} is the minimum feed rate and v_{max} the maximum feed rate allowed by the machine.

Method of Optimization

Optimization method of cutting parameter studied in this paper is on the basis of a given machine NC code. By optimizing the feed rate, we can make the output power of the machine spindle smooth and get the optimized NC code finally.

In another word, the optimization problems with constraints defined and designed in this optimization is to change the value v_f, so that we can get the optimized feed value v_f, so that we can get the optimized feed rate v_t satisfying $P(n, v_f, a_w, a_p) \approx P_0$. The process of optimization is shown in Figure 1.

1) Cutting data extraction

The secondary development tools Optipath API, provided by VERICUT software on the Visual Studio development platform, is used for the extraction and output of cutting parameters after the simulation of NC machining. The flowchart for cutting parameters extraction is shown in Figure 2.

Optipath API, the secondary development tool of VERICUT software, provides five Setup Function which can be invoked in the project file to set up the simulation environment. The executable .dll files are compiled after the completion of the project documentation.

2) Obtaining cutting power values by empirical formula

Empirical formula for milling force F_C and cutting power P_C is acquired as follows [1],

$$F_C = \frac{a_p^{x_F} f_Z^{y_F} a_e^{u_F} Z}{d_0^{q_F} n^{w_F}} C_F k_{F_C} \qquad (2)$$

$$v_C = \frac{n\pi(d_0 / 2)}{60} \qquad (3)$$

$$P_C = F_C \cdot v_C \qquad (4)$$

where a_p, a_e, d_0 represent the cutting depth, cutting width, milling cutter diameter respectively, with *mm* as units; f_z represents feed engagement, i.e., the moving distance of workstations per cut, and unit is *mm/z*; v_c represents the outer diameter of the cutter circumferential velocity, i.e., cutting speed in units of *mm/s*; *Z* represents the tool teeth; v_c represents tool speed and unit is *r/min*; x_F, y_F, u_F, q_F, w_F respectively empirical coefficients which associated with the cutting parameters; C_F and k_{Fc} are for the cutting force modified coefficients as the cutting condition changed.

We can obtain the cutting force of NC machining process by empirical formula, with the cutting data from VERICUT simulation processing.

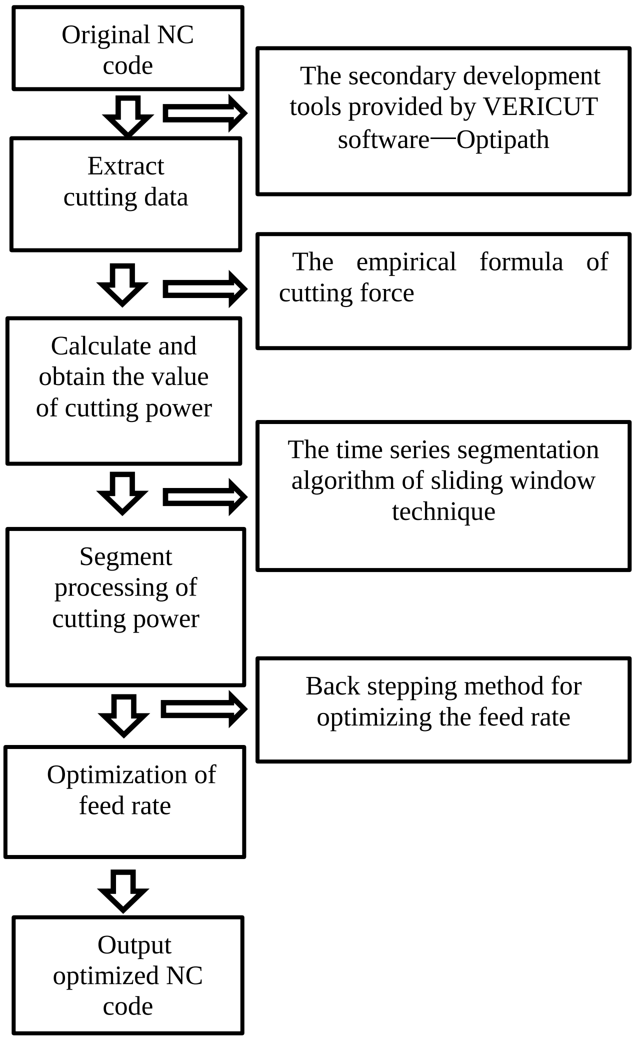

Figure 1. Flow chart of CNC machining parameter optimization

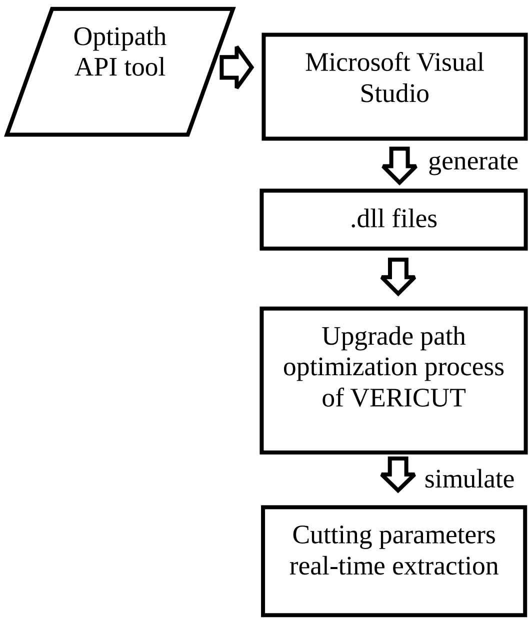

Figure 2 . The flowchart for cutting parameters extraction

Table 1. Part of important OptiPath API secondary development functions

Setup Function	void opapi_set_initialize_function(OPAPI_InitializeFunction);
	void opapi_set_optimize_function(OPAPI_OptimizeFunction);
	void opapi_set_terminate_function(OPAPI_TerminateFunction);
	voidopapi_set_tool_change_setup_function(OPAPI_ToolSetupFunction);
	void opapi_set_user_data(void *);
Utility Function	double opapi_get_axial_depth(void);
	double opapi_get_program_feedrate(void);
	double opapi_get_spindle_speed(void);
	void opapi_get_radial_width(void);
	void opapi_write_out_comment_line(char *);

3) Cutting power segmentation

Segment processing of spindle power output is one of the important steps in cutting parameter optimization technique. The main reasons are as follows,

a) There is usually a large amount of cutting power data during NC process, which may change with regularity or stay the same. We can classify the values remaining unchanged or changing in the same way as a unit time period according to the variation in values. It will take a huge amount of computation if described with all data points.

b) There will be some local features influenced by some factors in NC machining process. For example, when a machine or tool vibration is present and power output begins to increase or decrease sharply at some point, we might lay emphasis on global features and ignore the change in details in the study of cutting power.

Based on the time series segmentation algorithm of sliding window technique, the cutting power values are classified as a whole and segmented according to the clustering results. Optimization of the cutting feed rate is then implemented on the basis of power division.

Time series segmentation means that the time series S of length n is divided into k parts ($k \leq n$) and then characters of each segment are described and denoted as $S_i(1 \leq i \leq n)$, where data ought to be as closely as possible[5].

Sliding window model is acquired when the segmentation is carried out in a circular way and grow constantly until it exceeds a certain limit， with each data not contained by the latest segment processed[2]. In this paper， we adopt the sliding window algorithm to make cutting power segmentation in order to segment all the cutting power and divide similar power values points into the same period. Sliding window algorithm starts a new segment from the first point of the time series. It continued to grow forward until the distance between the point and the first point of this segment exceeds a specified threshold of time series. Then this segment ends and a new segment starts at the next sequence point. The above process is iterative until the end of time series. The key issue in this algorithm is the determination of threshold and distance between two points.

There are two ways of threshold determination in segment limit error algorithm. One is to ensure the maximum error of each segment no more than a user-specified threshold and the other is to make all segmentation errors less than another user-specified threshold. We choose the latter way according to the actual machining conditions and determine threshold values based on the requirements of error values.

Distance measurement is used to evaluate individual distance in space. Larger distance means farther individual variations. For numerical time series, Euclidean distance is the most simple and widely used one. It measures the absolute distance between the points in a multidimensional space. Suppose that $x_i = (l_{i2}, l_{i3}, \ldots, l_{im})^T, x_j = (l_{i2}, l_{j3}, \ldots, l_{jm})^T$ are two points in a m-dimensional space, it performs as follows,

$$d_{ij} = [\sum_{k=1}^{m} \left| x_{ik} - x_{jk} \right|^2]^{\frac{1}{2}} \tag{5}$$

We use Euclidean distance to calculate the similarity between two data points.

The following is the similarity calculation procedure of time series clustering:

Step 1: partition a new clustering S_i ;

Step 2: read in a group of cutting data, calculate the cutting power based on the empirical formula and record it as q_i;

Step 3: compare the distance d between the current data point q_i and the first data point of the current clustering. Go Step 4 if d is less than the threshold value C, otherwise go to Step 5;

Step 4: add q_i to S_i and proceed to Step 2;

Step 5: mark the previous data value as the end of current cluster and the current data value as the starting point of next sequence, then go to Step 1.

4) The optimization of cutting feed rate

According to the empirical formula mentioned above, if the feed rate changes and other parameters keep constant, the relationship between cutting power and feed rate can be simplified as,

$$p_C = k_c \cdot v_f^{y_F} \tag{6}$$

Given the current cutting power p_c and the assumed target value p_0, with other parameters unchanged, the computational equation of the optimized feed speed can be simplified as,

$$v_0 = {}^{y_F}\sqrt{\frac{p_0}{p_C}} \cdot v_f \tag{7}$$

where the calculated feed rate is required to meet the optimization constraints.

Optimization examples

Now, take a piece of given NC code for example, the cutting parameter optimization methods provided herein was used to optimized it, then a comparison between the NC codes before and after optimization was made. As shown in Table 2. Wherein, assume that the target power value p_0 is set to *580W* based on the actual processing needs.

Table 2. The optimization results

The original NC code	The optimized NC code
• • • • • •	• • • • • •
N0050G01Y38.1F380.	N50G01Y25.07F330.00
• • • • • •	• • • • • •
N0120Z19.05	N230Z19.05
N0130G01X50.8F380.	N240G01X11.70F330.00 N250X16.71F49 N260X21.72F28 N270X50.80F26
N0140X101.6Z44.45	N280X55.26Z21.28F28 N290X59.71Z23.51F31 N300X64.17Z25.73F35 N310X68.62Z27.96F39 N320X73.08Z30.19F45 N330X77.54Z32.42F52 N340X81.99Z34.65F61 N350X86.45Z36.87F74 N360X90.91Z39.10F90 N370X95.36Z41.33F116 N380X99.82Z43.56F158 N390X101.6Z44.45F206
N0150X254.	N400X104.61F234 N410X120.65F257 N420X188.83F330

	N430X193.84F270 N440X219.91F257 N450X254.F330.00
• • • • • •	• • • • • •

The spindle output power curves before and after optimization are shown in Figure 3. In the figure, the solid curve is the cutting power curve before optimization, and the dashed one is the curve after optimization. The optimized power curve becomes closer to the target power and smoother. So, the requirement for a smooth output of spindle power was achieved. Not only the maximum utilization of the power of the machine was realized, while the quality of parts was significantly improved, but also an effective way of ensuring the safety of NC systems was provided.

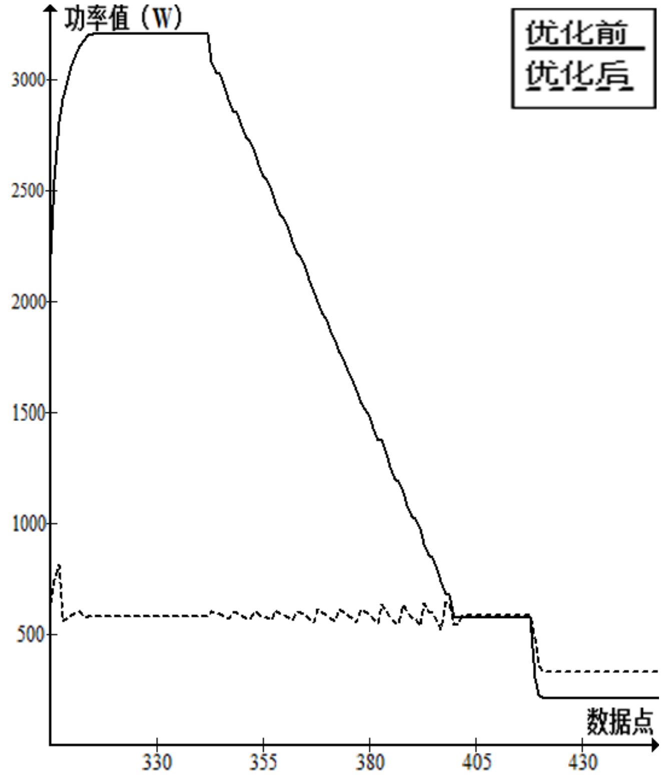

Figure 3: The spindle output power curves before and after optimization

Conclusion

Aimed at aviation user requirements and technical characteristics, it is of great significance to study on the technology of process parameter optimization and processing procedures and its application, with domestic high-end CNC machine tools as the research object. Based on the given complex processing code of metal structures, we did some superficial exploration to maximize the machine spindle to keep the curve of its output power smooth. We can obtain a relatively smooth output power by the optimization of feed speed while it may sometimes make the optimized feed speed lower than the minimum allowed value. At this time, further optimization is required to guarantee the processing effect. However, much more research needs to be done on the optimization of processes.

Acknowledgements

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