Title:
Optimization of Barrel Cutter for Five-axis Flank-milling based on Approximation of Tool Envelope Surface

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Introduction:
The machined surface in flank milling is formed by the swept envelope of the cutter surface. The true machining errors are the deviations between the cutter envelope surface and design surface. Recently increasing attention was drawn to non-single curvature tool which has different curvatures in different positions and gestures. Thus, the cutter envelope surface can approach to the design surface as perfect as possible by adjusting the tool position and gesture at contact point. As a result, the material removal rate and the precision can be increased at the same time.

Chaves-Jacob et al. [1] proposed a novel approach that optimizes the tool shape for a given trajectory-surface pair to reduce the interferences. Gong et al. [2-3] determined the optimum CL by least squares (LS) fitting of a spatial line to a series of post-processed point data. This method could smooth the error distribution in the normal section along the feed direction, but it can't control the errors between the cutter envelope surface and design surface in regions near the contact point. Wang et al. [4] proposed a flank milling tool positioning method based on an offset point of the designed surface with the excess error is nearly equal to the allowed error. Most work focus on the optimization of tool paths from the perspective of increasing machining accuracy, avoiding interference with fixed cutter. Only a few works pay attention to increase the machining precision by approximating the cutter envelope surface to designed surface. A new method to optimize the tool shape for five-axis flank milling is presented in this paper.

Main idea:
This paper fit the barrel cutter model with parameters approaching the design surface with the spatial point cloud by approximation theory. There are two principle parameters determining the envelope surface shape of barrel cutter: the radius of the generatrix and the maximum rotating radius. So the main work in this paper is optimizing the two parameters to make the mum of the unsigned deviations between the cutter envelop surface and the design surface least.

Fig. 1 shows the local tool coordinate system which is represented by $(\mathbf{x},\mathbf{y},\mathbf{z})$ where $\boldsymbol{O}$ is the tool center and $\mathbf{y}$ is the unit principle direction along the tool axis. In this coordinate system, the envelop surface of the barrel cutter $S_c(x,y,z)$ can be written as:

$$\sqrt{x^2+z^2}=\sqrt{R^2-y^2}-\ R-r \tag{1}$$

where parameter R and r are the radius of curvature of the generatrix and the maximum rotating radius respectively.

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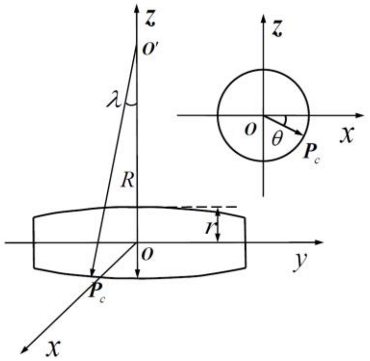

Fig. 1: Geometrical definition of barrel cutter.

First, the design surface should be transferred into discrete points. Based on the adaptive curvature match, the initial tool surface S_0 can be obtained according to the curvature information of the discrete points in the designed surface. To improve the computational efficiency, choose the discrete points every t points as the contact points P_s for optimization where t is the number of the neglected points. Then, calculating the unsigned deviations ε_i between the tool envelop surface and the discrete points near P_s . The points $P_i(\varepsilon_i \le \delta, 0 \le i \le n)$ are reserved as the initial data points for fitting.

In this paper, we adopt least squares (LS) criterion to solve the approximation problem, which can be expressed as

$$E = \frac{1}{n}\sum_{i=1}^{n}\varepsilon_i^2 \tag{2}$$

ε_i denotes the machining error at point P_s . To guarantee the precision after optimization, the unsigned deviation is calculated along the normal vector of the contact point in design surface instead of that in tool surface.

Although the cutting range at point P_s is expanded after the fitting above, iteration is needed to obtain the optimum parameters. The surface S' of new tool envelope surface after the first fitting process can be seen as the new initial envelope surface S_0 for next optimization and repeat the process above until

$$\left|E_{i+1} - E_i\right| \le \xi \tag{3}$$

which means the calculated result become stable with the growth in the number of iterative calculations.

The optimization of tool parameters at one contact point is implemented as described above, but for whole design surface, the optimum parameters R and r are $R_{\min}$ and $r_{\min}$ among all the computing result at each point P_s . The experimental validation for free surface with the optimized tool is shown in Fig.2. The results of the validation show us the optimization method proposed can improve the machining efficiency within the tolerance effectively.

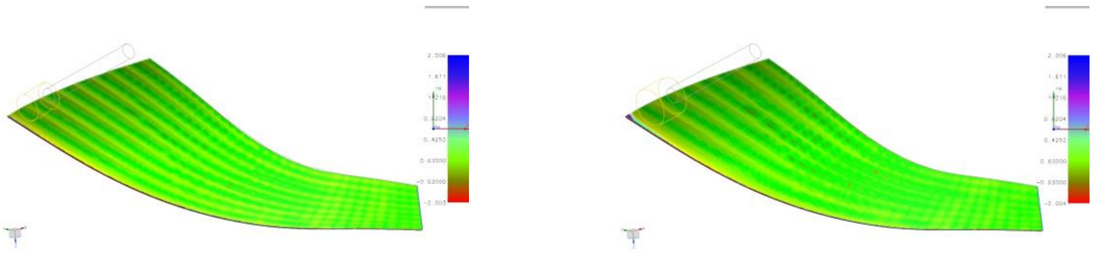

Fig. 2: Tool path with initial cutter (left) and optimized cutter(right).

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Conclusions:

This paper proposed a global tool parameter optimization method for five-axis flank milling barrel cutter. In this method, the tool envelope surface is optimized to approach the design surface by fitting the discrete points near contact point. While the amount of the data points is large, the computation is complex in this method, so there is further study on improving the calculative efficiency.

References:

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