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# Research of Uncut Free Pocketing Tool-path Generation Algorithm for High-speed Milling

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**Abstract.** In the rough machining process, contour-parallel is the most popular machining method. However, there is an issue of detecting and removing uncut regions. Though the importance of the uncut problem in pocket machining has long been recognized, there are few investigations that have been reported on detecting and removing uncut regions. This paper presents a tool-path generation algorithm on automatic recognition uncut free pocketing for High-speed Milling (HSM). In machining operation, uncut free pocketing is automatically recognized by the use of the algorithm. Empirical tests show the algorithm works efficiently and stably.

## Introduction

High-speed Milling (HSM) is a new technology revolution following up the technology of numerical control (NC) in machine tool manufacture circle. And it is inevitable that HSM rises with many developed technologies including machine tool structure, cutting-tool material, machining processing, CNC system and programming. At present, it isn't prevalent that the technology of HSM is applied because of no cutting-tool operating on tool-path that is generated by conventional CAM [1] as well as expensive machining cost. So it is imperative to research and develop CAM for HSM. The organization of the paper is as follows: firstly, make a summary of NC programming strategies; next, present the proposed algorithm of tool-path generation used to rough machining; thirdly, illustrate the example of tool-path generation by the algorithm; finally, draw a conclusion.

## NC Programming Strategies for HSM

HSM is a quite compositive technology, the special machining processing of which has completely changed conventional machining strategies. Therefore, when tool-path for HSM is planned, several special factors must be considered as follows: (1) Had better adopt helix or zigzag approach mode, and avoid plunge into material; to retracting mode, may as well adopt tangent-arc, and retracting tool-path coming back to clearance along curve. (2) For moving cutting-tool between parallel tool paths and lifting cutting-tool across machining regions, had better adopt curve as bridge, avoid using straight-segment connecting them. NURBS should be firstly adopted to connect two tool paths between cut levels [2]. (3) The curve of generated tool-path must be continuous and smooth in order to avoid making an abrupt change in direction.

Presently, many scholars are very interested in HSM technologies [3-5]. Relatively, however, the technology of NC automatic programming for HSM is less concerned. We analyzed quite a few CAD/CAM software including Powermill, Cimatron, Mastercam and UG. Empirical tests show it isn't certain that tool-path which they generated is rather perfect for HSM. By view of those, we have been researching the optimization algorithm of tool-path generation for HSM, so that machining tool-path is more reasonable and efficient.

## The Algorithm of Tool-path Generation

**Issues.** In pocket machining operation, contour-parallel method should be selected first. It has many advantages, however couple with two troublesome issues [6]:

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1. a robust two-dimensional (2-D)-curve offsetting algorithm;
2. detecting and removing uncut regions.

The 2-D-curve offsetting algorithm solution has been widely researched, because it has so many potential applications. However, though the importance of the uncut problem in pocket machining has long been recognized, there are few investigations reported on detecting and removing uncut regions.

**The Tool-path Generation Algorithm on Automatic Recognition Uncut Pocket.** These days, resolving the problem of reducing and removing uncut regions, not only in conventional NC machining but also in HSM, usually adopt the method that cutting-tool overlap portion is augmented at the cost of spending cut time. S.C. Park and B.K. Choi proposed *expanded PWID offset algorithm* [6] to removal machining uncut regions (Fig.1). L.L. An presented *appended clear-up path algorithm* [7] to removal machining uncut regions (Fig.2). However, as generated tool-path by them isn't continuous and smooth, they are unsuitable for HSM. So, we proposed an algorithm of tool-path generation for HSM. The overall procedure of which is as follows:

1. Pick up entities inside view-window, if no entity, sent message that shows no entity picked; otherwise, take *i*th (*i*=0,1,…,n-1)entity feed in closing-wire list according to the order : From edge start-point to edge end-point, and then generated closing-wires change into entities which are feed in entity list, then clear closing-wire list, setting *i*=*i*+1, if *i*<n, into program paragraph circle; if not, jump into next step.
2. If entity number is 1 in entity list, and then call the function body on pocketing wire with no island wire, which works the following Fig.3, Jump to next step; If entity number is bigger than 1, then call the function body on pocketing wire with island wires, which works the following Fig.4, jump to next step; otherwise, show error.
3. Release memory occupied by temporary tool-path lists; make certain the order of tool paths.

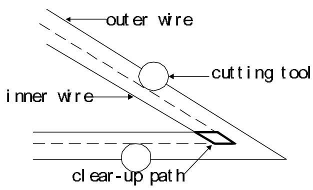

Fig.1 Diamond clear-up paths

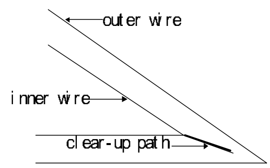

Fig.2 Straight-segment clear-up path

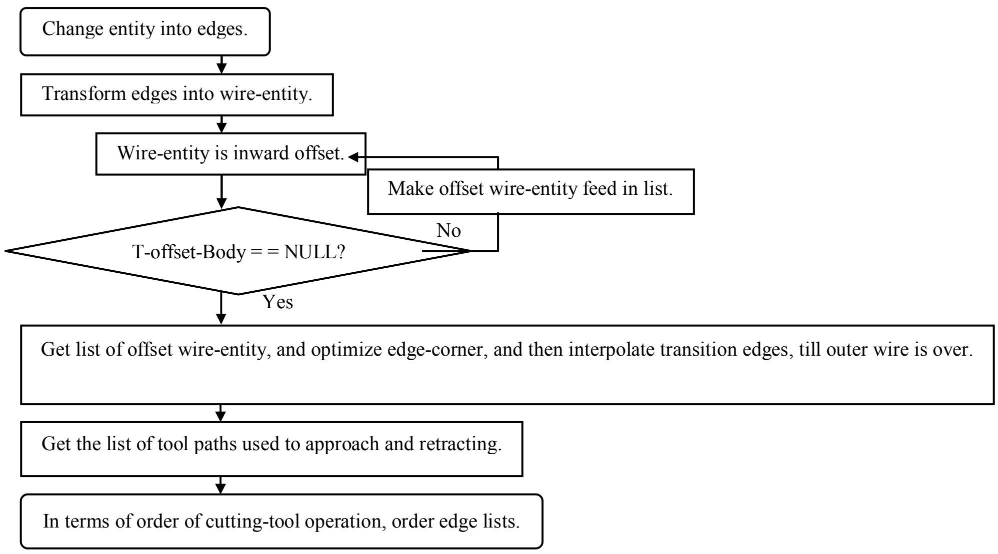

Fig.3 The flow chart with no island

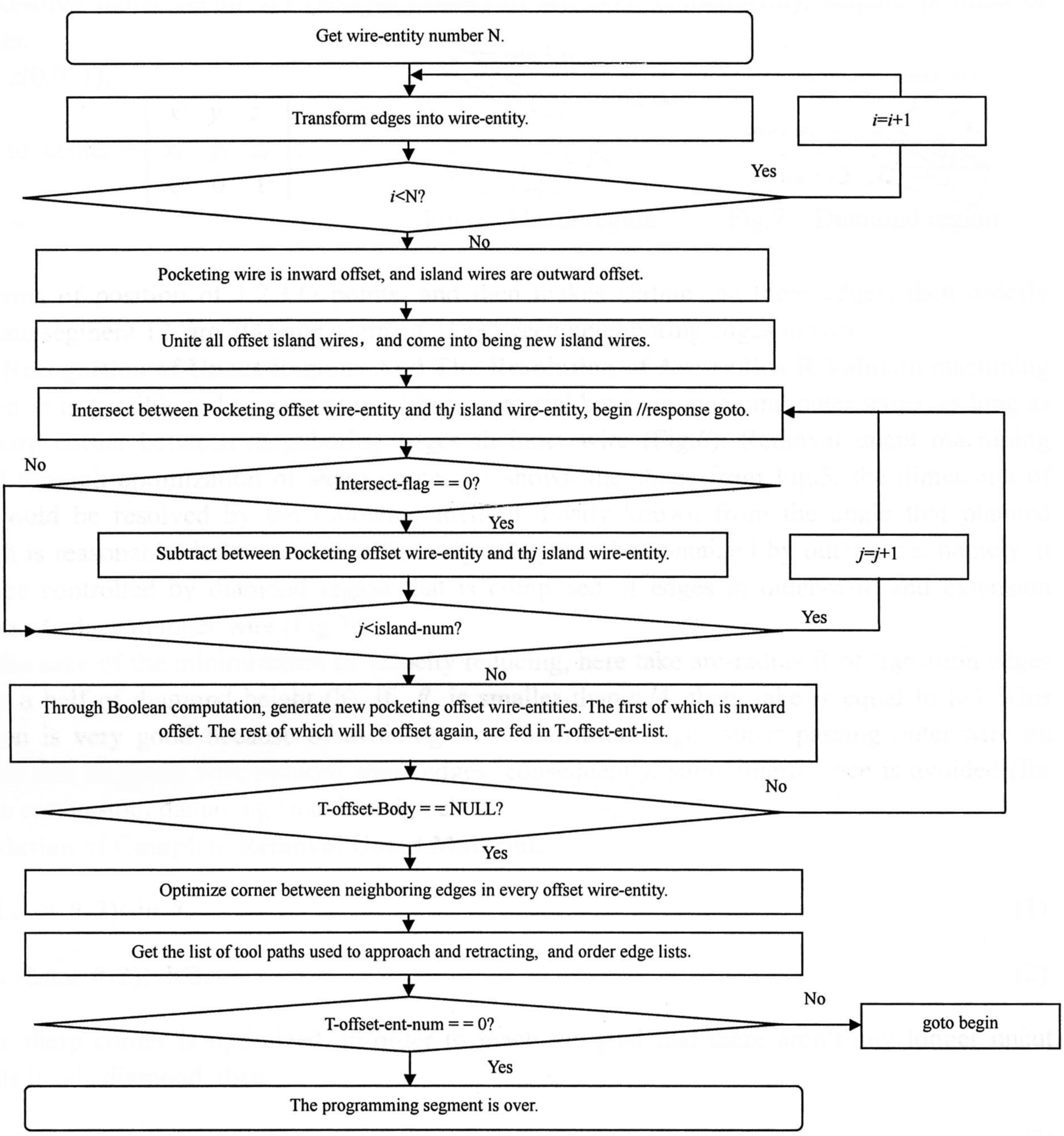


Fig.4 The flow chart with islands

**The Method of Optimizing Sharp Corner.** When there are sharp corner between any neighboring edges, orderly interpolate straight segment, circle segment and straight segment. The method of interpolating these edges is as follows:

Assume straight segment 12, circle segment 2O3, straight segment 31, in turn, on behalf of the three edges; □213 expresses $\theta$, R expresses arc-radius. The position of 1 point is known (Fig.5).

(1) Resolve $\theta$ (radian).

The $i$th edge end-point unit-vector: Vect_end ($x_i$, $y_i$, $z_i$), the $i$+1th edge start-point unit-vector: Vect_start ($x_{i+1}$, $y_{i+1}$, $z_{i+1}$), $\cos\theta_1$= Vect_start·Vect_end, $\theta=\pi-\theta_1$.

(2) Resolve two edge vectors of straight segment 12 and straight segment 31, consequently, acquire position of 2 and 3 points.

Vector vect_temp12= Vect_end ×R/tan ( $\theta$/2), vector vect_temp31= Vect_start ×R/tan( $\theta$/2).

(3) Resolve radial vector 2O (vect_to_center) of arc 2O3, consequently, acquire position of arc-center.

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w_v_z(0, 0, 1),

$$vect\_to\_center = \begin{vmatrix} x & y & z \\ x_i & y_i & z_i \\ 0 & 0 & 1 \end{vmatrix}.$$

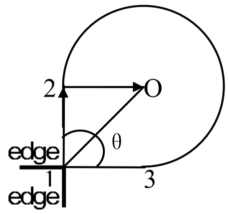


Fig.5 Optimization

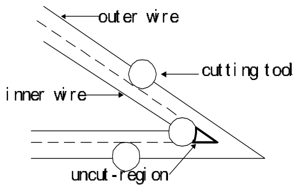


Fig.6 Uncut region

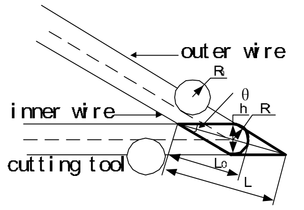


Fig.7 Diamond region

In terms of position of 1, 2, 3, O points, and then makes certain the three edges, then orderly interpolate segment 12, arc 2O3 and segment 31 between neighboring edges in wire.

**The Recognition of Uncut Regions and the Resolution of Arc-radius R Value.** In machining operation, it is possible to leave uncut machining material between inner and outer wires, as long as exist sharp corner between neighboring edges in inner wire (Fig.6). Removal uncut machining material through optimization of sharp corner, as shown the shape from Fig.5, the dimension of which could be resolved by the following method. Easily known from the angle that planned tool-path is reasonable, inner-wire transition edges ought to be contained by outer-wire, namely, it should be controlled by diamond region that is composed of edges in outer-wire and extension segments of edges in inner-wire (Fig.7).

For the sake of the minimization of velocity reducing, here take arc-radius R of transition edges equal to a half of diamond height (h). If $\theta$ is smaller than $\pi/4$, then, take R equal to h/4. This resolution is very good because of avoiding some transition edges super passing outer-wire on condition that an offset wire reduced some edges; consequently, some interference is avoided (for example cutting-tool damaging islands and pocket).

**Validation of Complete Removal Uncut Material.**

$$L=2h\cos(\theta/2)/\sin\theta. \quad (1)$$

$$L_0=h/(2\sin(\theta/2))+h/2. \quad (2)$$

After sharp corner is optimized, in order to reach the goal that there aren't any longer uncut materials inside diamond, then:

$$L-L_0\leq 2R_0. \quad (3)$$

From Eq.3, if values from both sides are equal, uncut region just be completely removed.

In row spacing, if cutting-tool overlap rate ($\eta$) is overlooked, then, $h=2R_0$. Acquired result: $\theta=0.21\pi$ ($39^o<\pi/4$). If $\eta$ is considered. And if $\eta$ is 25%, $h=3R_0/2$, then, $\theta=0.18\pi$ ($32^o$); And if $\eta$ is 50%, $h= R_0$, then, $\theta=0.13\pi$ ($23^o$).

Seen from these data, uncut region could be completely removed as long as the value of angle contained by two edges is bigger than θ.

According to computation and objective fact, we easily know that the value of edge-angle is usually bigger than $\pi/4$. However, smaller corner maybe arises in offset wire since Boolean operation. So the method of optimizing sharp corner could be primly in harmony with a pair of contradiction: "as the tool-path interval increase the total length of tool paths decreases, and consequently machining efficiencies increase; however, the tool-path interval larger than tool radius may leave uncut regions". Thus, it is available to HSM and uncut region removal.

**Advantages of the Algorithm.** (1) Adopt helix approach and tangent retracting mode (Fig.8), thus, reduce damp vibration from machine tool, and protect cutting-tool from damage. (2) For moving cutting-tool in row spacing, adopt bi-arc transition as well as the transition used by outward arc and straight segments (Fig.8), as result, this strategy makes certain that all tool paths are smooth and continuous ($C^1$), and that cutting-tool operates at high and stable feed-speed.

**Experiment of Tool-path Generation Algorithm.** The algorithm has been perfectly realized in module for HSM existing in Superman 2000 CAD/CAM software. Through test (Fig.8, Fig.9), results show it works efficiently and stably.

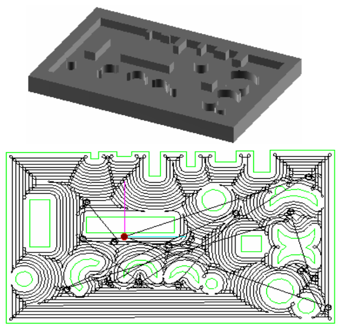

Fig.8 Tool-path with no island

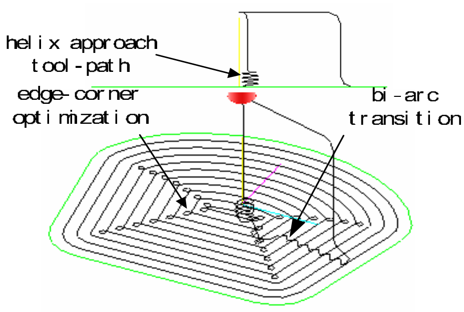


Fig.9 Tool-path with islands

## Conclusion

Automatic recognition uncut regions tool-path is a kind of selection used to rough machining for HSM. It takes an important role to the development of automatic NC programming technology. This paper presented the algorithm of Automatic recognition uncut regions tool-path generation which not only makes material removal become efficient, but also makes uncut regions removal become reasonable.

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