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TOWARD THE AUTOMATION OF THE PLUNGE MILLING STRATEGY FOR ROUGHING SCULPTURED SURFACES FROM STL MODELS

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ABSTRACT
Part with sculptured surfaces is obtained in three stages: roughing, semi-finishing and finishing. The roughing operation consists in using flat end tools or fillet end tools on sequential horizontal cutting planes to remove the most material from the raw part as rapidly as possible using "Parallel Planes" or "Offset Contours" machining strategy. When roughing deep parts, radial cutting forces, vibrations and tool bending are important. To avoid these disadvantages, the "Plunge Milling" strategy is developed. The complex geometry of sculptured surfaces makes the tool path generation without interferences and collisions a very difficult task. In this paper, an automated methodology is proposed for roughing any part with sculptured surfaces from its STL model using "Plunge Milling" strategy on 3-axis CNC milling machines. After the specification of the principal parameters (stock allowance, radial cutting depth, radial step, tool diameter and sweeping mode), the methodology determines: 1) intersection contours, 2) machined segments, 3) plunging positions without interferences, 4) plunge depth for each valid plunging position, 5) minimum tool length avoiding collision and finally tool path in « One-Way » or « Zig-Zag » mode.
Keywords: STL Model, Sculptured Surface, Roughing, Plunge Milling, Interference, Collision.

1. INTRODUCTION

Parts with sculptured surfaces are machined on 03, 04 or 05-axis CNC milling machines in three stages: roughing, semi-finishing and finishing. In the roughing operation, the most material from the raw part is removed as rapidly as possible by cutting on sequential horizontal cutting planes using "Parallel Planes" [1-2] or "Offset Contours" [3-8] machining strategy. When roughing deep parts, radial cutting forces, vibrations and tool bending are important. To avoid these problems, cutting conditions must be reduced, which decreases the material removal rate and increases machining time. Besides, the machining time for roughing hard materials, large and deep parts using the classic strategies is very important. To avoid these disadvantages, the "Plunge Milling" strategy is developed. In this strategy, the tool plunges axially into the part to rough it [9-13]. Roughing part with sculptured surfaces by this strategy requires selection of tool dimensions, identification of valid plunging positions, plunge depth for all valid plunging positions, minimum tool length avoiding collisions. The complex geometry of sculptured surfaces makes the tool path generation without interferences and collisions a very difficult task. In this paper, a methodology is proposed to automate the generation of the plunge milling tool path for roughing parts with sculptured surfaces from their STL models on 3-axis CNC milling machines. From the principal parameters (stock allowance, radial cutting depth, radial step, tool diameter and sweeping mode), the methodology determines: 1) intersection contours, 2) machined segments, 3) plunging positions without interferences, 4) plunge depth for each valid plunging position, 5) minimum tool length avoiding the collisions and finally the plunge milling tool path is generated in « One-Way » or « Zig-Zag » mode.

2. PROPOSED METHODOLOGY

2.1. Contours generation

Before the generation of the roughing tool path, the first step consists in delimiting the regions concerned by the machining. This delimitation is obtained from the determination of the intersection segments between the triangles of the STL model and a horizontal plane passing by the superior face of the raw part. For this, only triangles having strictly one side belonging to this plane are considered. From these segments, the contours composing the superior face of the raw part are constructed.

2.2. Machined segments identification

From the dimensions of the raw part, the radial cutting depth and the sweeping direction (along X-axis or Y-axis), the number of required passes is calculated. Then, for each pass, the segments where the tool can plunge (machined segments) are identified using the following steps (Figure 1):

- Calculate the intersection points between a line representing the pass with the contours and the limits of the raw part.
- Sort these points in an ancreasing order with regard to the sweeping direction.
- For each segment defined by two consecutive intersection points, its nature is determined by:
  - ❖ Associate a vertical line passing by the middle of the segment.
  - ❖ Calculate the intersection points between this line and the set of triangles.
    - ▪ If there is no intersection point, then the segment is machined.
    - ▪ If there are an intersection points :
      - ➢ Consider the highest intersection point along the Z-axis and test its position with regard to the superior face of the raw part:
        - o If it is below, then the segment is machined. Else, it is not machined.

2.3. Plunging positions determination

For each machined segment, the plunging positions without interfernce are determined from the stock allowance, the tool radius and the radial step. They are identified by the following steps (Figure 2):

- For each possible plunging position, center a circle with a radius equal to the tool radius.
- Test if there is an intersection between the circle and the segments of the contours.
  - o If there is no intersection, it is a valid plunging position. Else, it is an invalid plunging position.

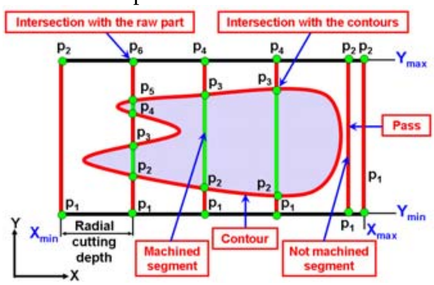


Figure 1. Intersection points and type of segments.

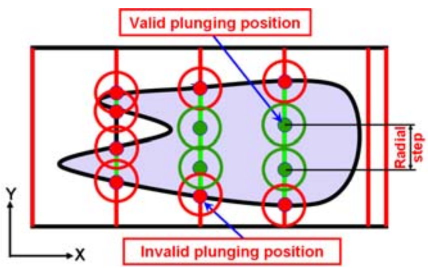


Figure 2. Type of plunging positions.

2.4. Plunge depth and minimum tool length

By reason of the complex geometry of sculptured surfaces, the plunge depth changes for all plunging positions. For a valid plunging position, its plunge depth is determined by these steps (Figure 3):

- Approximate the cylinder representing the tool by a set of an equidistant vertical lines.
- For each line, calculate its intersection points with all triangles.
- Calculate the plunge depth by considering the highest point along Z-axis for all lines.

To avoid the problem of collisions between the tool and the raw part, the minimum tool lenght is calculated from the maximum plunge depth for all valid plunging positions.

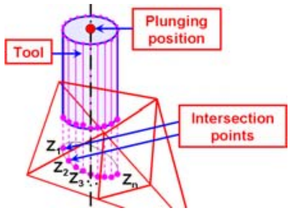


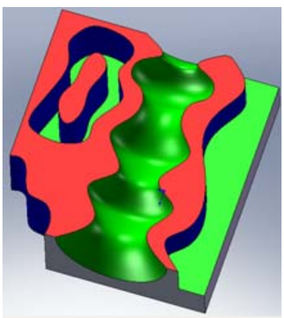
Figure 3. Plunge depth.

2.5. Tool path generation

In this work, the direction of tool sweeping can be along X-axis or Y-axis and for each direction the tool path can be generated in “One-Way” mode or in “Zig-Zag” mode. Besides, the joining of two consecutive plunging positions is done with a horizontal straight segment and the tool clearance is done along the Z-axis.

3. RESULTS

The proposed methodology has been implemented in an object-oriented software running under Windows using C++ Builder and the graphics library OpenGL. It is validated on an STL model generated from a CAD model of a complex part (Figure 4). This STL model is composed of 30190 triangles and 16231 vertices and the minimum dimensions of the raw part are 140mm×150×50mm. The determination of the contours shows that the superior face of the part is composed of 04 contours (Figure 5.a). This part is roughed using “Plunge Milling” strategy with the direction of tool sweeping is along X-axis. Stock allowance, radial cutting depth, radial step and tool diameter are fixed to 0.5mm, 2mm, 2mm and 3mm respectively. From these parameters, the intersection points, the segments types (Figure 5.b) and the plunging positions types (Figure 5.c) are determined. Based on the valid plunging positions, the minimum tool length that avoids collisions is 50mm. The plunging tool path is generated in “Zig-Zag” mode (Figure 6.a). To verify the tool path, a machining simulation is done (Figure 6.b). The obtained form of the part indicates that the tool path is correct and the part is roughed accurately.


a. CAD model.

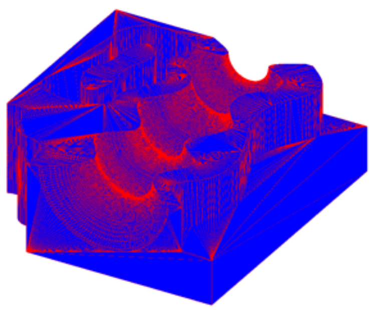
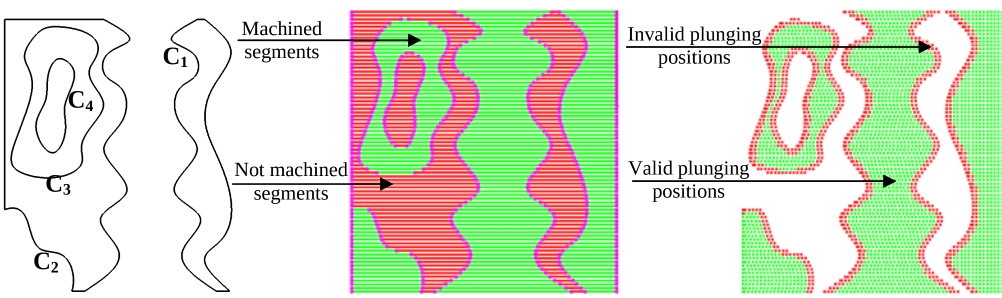
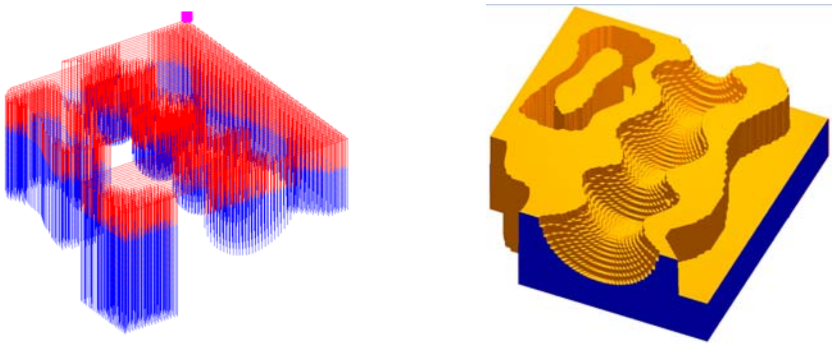

b. STL Model.

Figure 4. CAD and STL model of the part.



a. Intersection contours. *b. Segments types.* *c. Plunging positions types.*

Figure 5. Contours and types of segments and plunging positions.



a. « Zig-Zag » tool path. b. Machining simulation.

Figure 6. Tool path and machining simulation.

4. CONCLUSION

In this paper, an automated methodology is presented for roughing any part with sculptured surfaces using “Plunge Milling” strategy on 3-axis CNC milling machines. This methodology, permits from the STL model of the part and the principal parameters of the strategy (stock allowance, radial cutting depth, radial step, tool diameter and sweeping mode), the determination of: 1) intersection contours, 2) machined segments, 3) valid plunging positions, 4) plunge depth for each valid plunging position, 5) minimum tool length avoiding collisions. Finally, the tool path in « One-Way » or « Zig-Zag » mode and the associated machining program “G-Code” are generated. This methodology reduces the product development cycle by minimizing the necessary time to generate a valid tool path and hence the costs which increases the productivity.

In perspective of this work, the selection of the optimum tool radius for each contour, the combination of different tools dimensions and the use of different sweeping modes will be considered.

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