Research on Ultrasonic-Assisted CNC Cutting of Honeycomb Cores Based on UG

Dongfang Mu (mudongfang96@foxmail.com)
Hangzhou Dianzi University
Xiaoping Hu
Hangzhou Dianzi University
Haofeng Yu
Hangzhou Dianzi University
Baohua Yu
Hangzhou Dianzi University

Research Article

Keywords: Ultrasonic-assisted cutting, Honeycomb cores, ultrasonic cutter, post-processing

Posted Date: February 12th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-215937/v1

Version of Record: A version of this preprint was published at The International Journal of Advanced Manufacturing Technology on August 6th, 2021. See the published version at https://doi.org/10.1007/s00170-021-07820-x.

Abstract

Compared with traditional milling, ultrasonic-assisted cutting of honeycomb cores has the advantages of good surface quality and low cutting force. Because the ultrasonic cutter and chip shapes used in ultrasonic machining are significantly different from traditional machining methods. This study is based on UG CAM for process planning, which will be converted into codes that can be recognized by six-axis CNC machine tools through post-processing, and verify the feasibility through VERICUT simulation.

1 Introduction

Honeycomb cores have excellent physical properties such as high specific strength, high specific stiffness, and high temperature resistance, and are widely used in the aerospace field. High-speed CNC milling is currently a relatively mature processing method for honeycomb cores, which has the advantages of high cutting efficiency and good surface quality [1]. Due to the characteristics of orthogonal anisotropy and heterogeneous structure of honeycomb cores. the traditional milling process will result in low processing quality, low processing efficiency, dust pollution problems, and the intervention of ultrasonic-assisted cutting effectively solves the disadvantages of traditional milling [2]. The research on the numerical control machining of ultrasonic-assisted cutting honeycomb cores is of great significance to improve the process planning of processing honeycomb parts and to promote the application and research of ultrasonic machining technology in the field of processing materials with weak rigidity such as honeycomb.

The cutters used for ultrasonic-assisted cutting are straight blade cutter and disc cutter. The cutting forms and cutting methods of these two cutters are completely different from traditional milling cutters. The shape of the cutters are thin blades, so a single pass can only separate the material on both sides of the blade, and cannot achieve material shedding. Because the technological characteristics of thin-edged cutters are different from traditional tools. In order to obtain a tool path with a small cutting depth and regular chips, and to improve cutting efficiency, it is necessary to separately modify the tool path of odd and even layers by planning the order of cutter location (CL).

Post-processing technology refers to converting the planned tool path into a code that can be recognized by the machine tool control system, which is used for machine tool numerical control simulation or machine tool processing [3]. At present, many post-processors provided by software can be customized for special model machine tools to develop special processors for the machine tools [4]. When the general-purpose post-processor can't meet the use requirements, the post-processor can be independently developed. In recent years, some researchers have been developing and researching the post-processing algorithms of five-axis machine tools with different structures. Li Lijun [5]and others took the machine tool structure of Hamer C20U model five-axis vertical machining center as an example, and successfully developed a five-axis post-processor for Heidenhain dual-turntable based on UG6.0 and passed simulation verification. Li Tiegang [6]proposed a method for customizing the post-processor of a five-axis machine tool based on Edgecam programming and verified it by an example. Hao Qiaomei [7]and others proposed a custom modification for the post-processing of Master CAM software for AC double-swinging five-axis machine tools, and verified it by taking five-axis drilling as an example. In order to solve the problem of post-processing of a five-axis machine tool with dual rotary tables from workpiece coordinate system to machine tool coordinate system, Daoyang Yu [8] proposes a solution method namely Two Circle Spherical method (referred to as TCS).

In this research article, Section 2 introduces the CNC cutting process of ultrasonic assisted machining, including rough machining process planning and finishing process planning. In Section 3, the key technology of ultrasonic-assisted cutting CNC programming is introduced. UG CAM is used for preliminary process planning, and then post-processing planning will be carried out. In Section 4, a cutting simulation experiment is carried out based on VERICUT to illustrate the effectiveness of this method.

2 Analysis Of Nc Cutting Process Of Typical Parts

The application of honeycomb cores in the aerospace field includes wings, spoilers, etc. The surface of honeycomb parts is generally a curved surface with small curvature and smooth changes [9]. An example part is shown in Fig. 1. This part contains flat, inclined, convex, concave and other features, and is a typical honeycomb part that is representative in the aviation manufacturing field.

2.1 "V" shaped process for rough machining

According to the research in the existing literature [10], the "V" processing technology is preferred. As shown in Fig. 2, a straight blade cutter cuts twice with the same swing angle and inclination angle (in the tool coordinate system), and the cutting surface is formed into a "V" shape (triangle and diamond chips). The use of this cutting method is often used in the roughing process, and the cutting efficiency is high.

Ultrasonic-assisted cutting uses a straight blade cutter, and its process planning process is quite different from traditional tool, especially the selection of procedures and the setting of processing parameters such as step and cutting depth are quite different from conventional settings. Key steps of "V" shape roughing process planning:

(1) Select cavity milling as the processing procedure;

(2) Equivalent replace cuttter, which is equivalent to a slender cylinder milling tool, as shown in Fig. 3;

(3) Set cutting parameters: 1) Step distance, cutting depth,

$$f = 2d\sin\alpha + e/\cos\alpha \quad , \; a_p = \frac{d}{\sqrt{\tan^2\alpha + \frac{1}{\sin^2\theta}}} \; ,$$

Where d is the axial cutting depth of the tool, α is the yaw angle, θ is the rake angle, and e is the blade thickness; 2) the margin is set to 0mm;

3) The cutting starting point is set at the corner with the largest vertical cutting amount of the blank, so that the starting toolpaths of the upper and lower layers are aligned;

2.2 Finishing process planning

The finishing process of ultrasonic-assisted cutting is mainly the disc cutter finishing process. Because the cutting form of the disc cutter is rotary motion, and its high-frequency vibration along the cutter axis has little relevance to the process planning method, UG can be used for complete process planning. Its key technology:

(1) Select variable contour milling as the processing method;

(2) Equivalent replace cutter, set the disc cutter to the same diameter cylinder milling tool, as shown in Fig. 4;

(3) Select the driving of the surface area as the driving method, and carry out independent planning according to the different surface features of the part surface;

(4) Cutting angle, set a smaller rake angle and yaw angle to reduce the generation of cutting heat.

3 The Key Technology Of Ultrasonic-assisted Cutting Cnc Programming

For the "V" shaped rough machining process, first use UG CAM for preliminary process planning, and then post-processing planning. Adapt the initial code output by UG based on MATLAB compiler software. For the finishing process, use UG CAM to directly plan the path for the ultrasonic disc cutter and generate a CNC program that can be used for machining.

3.1 Second arrangement of CLs

In the "V" -shaped machining process, to obtain a tool path with a small cutting depth and uniform chip formation, forming a diamond-shaped cross section, the tool path between the odd and even layers can be misaligned by 0.5f.

In the second layout process, the tool path of the odd or even layer is translated in the Y direction to form the odd and even layer cutting, then the single cutting can only realize one of the "V" shaped edges in the "V" shaped processing technology. One side, and the other side needs to be cut on one side of the layer after changing, change the straight blade cutter swing angle and cut again along the same tool path, as shown in Fig. 5-b, Fig. 5-c; there will be a Y-empty situation.

The step distance is set to 0.5f, as shown in Fig. 6-a. In the second layout process, the CL of the odd and even layers are re-arranged respectively, and the tool path with the step distance of f is deleted. In a single-line tool path After cutting, change the tool angle and return along the original tool path. The order of the parity layer passes is shown in Fig. 6-b and Fig. 6-c respectively. Increased cutting efficiency. First set a step size of 0.5f. After cutting and editing the tool path, all tool paths have not been translated, and it is still based on the precise tool path formed by the original surface to improve processing efficiency.

The technical route of the CL sequence of the initial code is adapted, as shown in Fig. 7.

(1) Read the code line by line. The general idea of adapting the code is to use the "fopen" function to open the initial code document, and use the "fgetl" function to read each line of code line by line and form a string group, and then identify, judge, and adapt the content of each line of string.

(2) Distinguish between odd and even layers. The order of the CL of the odd and even layers must be adapted separately, so how to distinguish the odd and even layers is an important preparatory link. "EngageMove" represents the infeed. The Z coordinate of the infeed first appears in the next line of this mark. This coordinate represents the height of the current cutting layer in the Z direction, so it is feasible to distinguish the parity layer by the change of the Z coordinate value.

(3) Record the cutter counting location(CCL). As shown in Fig. 8, under the premise that the X axis direction is the cutting direction, if only the X coordinate appears in the current CL, it means that a new cutting tool path has appeared in the cutting order, and this CL is recorded as CCL ". Due to the complex surface problem, not every tool path is a straight line along the X axis. When the tool path is close to the curved surface, there will be more than one CL with only X coordinates in the same tool path, such as x_6 At this time, the CCL previously recorded in this tool path should be discarded and updated to the current CCL. As the turning mark of tool path, CCL is mainly used to delete and adjust the order of CL.

(4) Delete and adjust the order of CL. The odd-numbered toolpaths in the odd-numbered layers are reserved, and the odd-numbered toolpaths in the even-numbered layers are deleted, but the deletion method is the same. In odd-numbered layers, odd-numbered toolpaths need to be retained, and after the end of the toolpath, return along the original toolpath and enter the next toolpath, so start when the number of CCL is odd, record the point behind the CLs, and write in reverse order when the CCL is even.

(5) Delete the duplicate CL. After the adjustment of the CL sequence is completed, there will be a situation where the information of the current CL and the previous CL are overlapped, and the current one should be identified and deleted.

3.2 Research on information planning of lifting and lowering cutter

The code generated by the preliminary planning based on the cavity milling process using UG contains only three-axis CNC information, so there is no change in the angle of the rotation axis when the tool changes the tool path inside the part, resulting in no lifting of the tool path turning point within the lifting CL. Therefore, it is necessary to add the information of lifting and lowering the cutter, and the places where the cutter needs to be lifted include but not limited to the above situations. The main situations that need to lift the cutter are as follows, as shown in Fig. 9.

(1) the situation of continuous cutter lift. Fig. 10 is a schematic diagram of the tool lifting situation. The process from the CL P_1 to P_2 is the non-cutting process that the tool needs to lift. This kind of situation usually occurs when the tool path turns to the edge of the convex curved surface area. Point P_1 contains only X coordinate information and its absolute value is less than X_{max}, and the moving distance in the Y direction from the point P_1 to P_2 is greater than the moving distance in the X direction (that is, the angle φ between the stepping direction and the X axis direction is greater than the straight blade cutter, The limit value of the rotation angle of the surface in the workpiece φ_{max}). In this case, it is recognized at point P_1 that the cutter needs to be lifted. The CL lift should be added after P_1, and the position of the lower cutter should be added after P_2 (The next CL outside the blank should be added with the next cutter information), while adding the tool lifting information, since the process from the CL P_1 to P_2 is a non-cutting process, the rotation angle information of the rotary axis before the point P_2 should be deleted to improve work efficiency.

(2) The situation of area jump type cutter lifting. As shown in Fig. 10, the CL P_3 to P_4 are the process from the normal complete cutting area to the incomplete cutting area with convex curved surface. This process does not require cutting, and the tool needs to be lifted after the point P_3 to move to the point P_4. The judgment method in this case is that the point P_4 contains both X and Y coordinate information, the absolute value of the X coordinate is less than Xmax, and the amount of movement in the Y direction is greater than 0.5f. This situation is different from the situation (1). Situation 2 recognizes the need to lift the cutter at point P_4. The position of the cutter lifting position should be added before P_4, and the position of the lower cutter position is added to P_4. After adding the tool lifting information At the same time, delete the rotation angle information before P_4 to improve work efficiency.

(3) The tool path changes too much. As shown in the CLs P_5, P_6, and P_7 in Fig. 10, when a convex curved surface affects the tool path planning of the current layer but does not completely block the tool path, a single tool path will detour. There will be a situation where the angle between the small tool path and the X axis φ changes too much, as shown in the tool path of the point P_5 to P_6. The judgment method in this case is that the absolute value of the X coordinate of the point P_5 is less than X_{max}, and the angle between P_5P_6 and the upper tool path exceeds φ_{max}. The solution for lifting the cutter in this case is the same as the case (1). Because the surface of aerospace parts is very smooth, and the rough machining process has a large margin, the amount of overcut generated by deleting the curved section in this tool

path is very small (about 0.5mm), and will not affect the finishing process and the final part surface integrity.

Among them, X_{max} is the half of the maximum blank size in the X direction of the blank set in UG, and φ_{max} is the limit value of the rotation angle of the straight blade cutter face in the workpiece.

3.3 Research on planning of chip breaking toolpath

In the cutting process of "V" shape with ultrasonic straight blade cutter as the processing tool, when the entire tool path does not encounter the inclined surface, the straight blade cutter needs to complete the cutting twice to complete the chip removal; In the case of inclined planes, the chips can’t fall off after the straight blade cutter has been cut back and forth along this path, as shown in Fig. 11. This section will identify this phenomenon and add a chip breaking tool path. The key steps are as follows:

(1) Record the cutter location of chip breaker(CLCB). The position of the tool path that needs to be added with chip breaking is located at the tool lifting and lower CL studied in Section 3.2. Therefore, the CL with Z coordinate information can be found and recognized by identifying the CL coordinate information Determine the X and Y coordinate information of the current CL. If $x < x_{max}$ is met and the Y coordinate difference with the previous CLCB is less than 0.5f, record the current X and Y coordinate information and save as The CLCB is used for subsequent connection to become a chip breaker tool path.

(2) Supplement the command angle for the CLCB. The blade posture of the straight blade cutter for cutting chips is different from that of the "V" -shaped machining process. When cutting, the straight blade cutter only needs to include the forward inclination angle.

(3) Insert the CLCB. The chip breaking tool path is formed by adding the information of each CL to the code in sequence. The specific method is: if the CLCB appears in the current layer, the CLCB will be added after the "DepartureMove" sign appears at the end of the layer The chip location forms a chip breaking tool path.

(4) Raise the tool path to avoid interference of the tool tip. Tool tip interference can be avoided by raising the overall tool path.

4 Cutting Simulation Experiment Based On Vericut

The conventional code only needs to be pre-coded, and the six-axis CNC machining code such as ultrasonic-assisted cutting must be simulated by the machine tool to be able to perform subsequent processing. For the aerospace manufacturing field, VERICUT is selected as the numerical control simulation processing software.

4.1 Establishment of a motion simulation cutting model for a six-axis CNC machine tool

(1) Establish a six-axis gantry machine model

The initial model of the five-axis machine tool can be exported from the processing module in the UG software. Each axis of the model must be adapted before it can be imported into VERICUT. The ultrasonic tool holder (sixth axis) needs to be imported after manual modeling.

(2) VERICUT sets key points

a. Machine tool control system selection. Consistent with the post-processor in UG, 840D controller is also selected in VERICUT, and the controller supports six-axis CNC machining process.
b. The affiliation of each entity module is determined. For a six-axis machine tool with an ultrasonic tool holder, the ultrasonic tool holder is subordinate to the A axis as the sixth axis (third rotation axis) of the machine tool, and the angle of the ultrasonic tool holder is controllable, and the tool is included in the ultrasonic tool holder. The affiliation of the remaining physical modules is that the A axis belongs to the C axis, the C axis belongs to the Z axis, the Z axis belongs to the X axis, the X axis belongs to the Y axis, and the Y axis belongs to the non-movable machine tool body.
c. Equivalent setting of ultrasonic cutter. The formation process of the cutting effect in VERICUT is that the part of the rotary tool passing through the workpiece will disappear, and the straight blade cutter is a flat dagger cutter. In the simulation process, the use of an equivalent cylindrical milling cutter will result in the "V" machining process simulation process. Diamond chips cannot be displayed as chip loss. Therefore, it is necessary to add a simulated chip removal tool path after the end of each cutting layer. The tool is set to a tapered milling cutter, and the cone angle is the swing angle in the "V" shape machining process.
d. Angle range setting. In order to avoid the small rotation of the tool during the cutting process (such as -1 ° to 0 ° to 1 °) into a large rotation (such as -1 ° to 180 ° to 1 °), the control mode of the rotary axis must be set Set to the shortest distance.
e. Set comparison parts. VERICUT has an automatic comparison function and can export a complete and detailed process report, so the addition of comparative parts will effectively assist in the study of the feasibility of the adapted code.

4.2 Machine tool simulation and inspection of case parts

The post-processing modified simulation code is imported into VERICUT for machine tool motion simulation. During the process planning, the maximum cutting depth is set to 7.66mm and the step distance is 12.3mm. There is no interference between the tool holder and the workpiece during the motion simulation process. The rough machining simulation results are shown in Fig. 12. There is no over-cutting in the tip of the "V" -shaped tool path during cutting. To cut off the tool path to ensure smooth chip removal during cutting contains a small amount of over-cutting. Due to the huge gap between the residual entity and the traditional milling residual entity after the end of the "V" machining process, VERICUT cannot correctly measure its residual height. The residual height is sampled and measured in the software, and the maximum residual height is less than 10mm. The distance from the top of most diamonds to the curved surface is less than 8.5mm, which meets the requirements of finishing.

The disc cutter is equivalently replaced with the same-diameter cylinder milling tool and the finishing code generated is imported into VERICUT. The maximum residual height is set to 0.2mm during the process planning, and the spindle and the workpiece do not interfere during the motion simulation process. The simulation results of the finishing process are shown in Fig. 13, which is consistent with the cutting results of the pre-code simulation performed in the UG software.

The motion simulation process and results of the "V" machining technology machine tool show that the post-processed rough machining code can be used in the six-axis CNC gantry machining center and meet the ultrasonic cutter processing standards. The finishing results show that the process planning method based on ultrasonic disc cutter for complex areas divided into regions is feasible, and the processing results reach the expected standard.

5 Conclusions

This research proposes a post-processing method for CNC machining for ultrasonic-assisted processing of honeycomb cores. First select the "V" machining process and use UG CAM to make a preliminary process planning of the "V" machining process, use the 840D post-processor to generate a preliminary three-axis code, and the finishing process is directly replaced by the tool to generate a machinable Code. Secondly, the code is post-processed according to the technological characteristics of the ultrasonic straight blade cutter in the "V" machining process to generate a six-axis code containing motion information of the ultrasonic tool holder. Three key technologies: Second arrangement of CLs, research on information planning of lifting and lowering cutter, research on planning of chip breaking toolpath. Finally, the code processed by the post-processing module successfully confirmed its feasibility through the VERICUT six-axis CNC machine tool motion simulation.

Declarations

6.1 Funding

This study was funded by the National Natural Science Foundation of China (No.51975173)

6.2 Declaration of conflicts interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this paper.

6.3 Compliance with ethical standards

(1) The manuscript was not submitted to more than one journal at the same time.

(2) This study does not involve human participants and animals.

(3) Author(s) are informed and consent to participate and publish.

(4) The data and materials in the paper are availability.

6.4 Authors contributions

Xiaoping Hu and Baohua Yu planned the research. Haofeng Yu and Dongfang Mu did experiments and analyzed the data. Dongfang Mu wrote the paper.

References

1. Wang F, Wang Y (2018) Investigate on milling force of cryogenic cooling processing aluminum honeycomb treated by ice fixation. Int J Adv Manuf Technol 98(5–8):1-13
2. Di Kang, Ping Zou, et al. (2019) Study on ultrasonic vibration-assisted cutting of Nomex honeycomb cores[J]. Int J Adv Manuf Technol 104, 979-992.
3. Xuliang Pan (2019) Four-axis complete machining process planning and tool path post-processing of complex curved impeller. Master's degree thesis of Xi’an Shiyou University
4. Jia Li, Xinxiong Zhu (1996) General Post-processing System Intrduction. Digital Manufacturing Industry (6):19-21.
5. Lijun Li, Wei Sun (2014) Research of Postprocessor for Heidenhain Dual-table Five-axis Machine Based on UGNX6.0. Machine Tool & Hydraulics 42(10):122-125
6. Tiegang Li (2014) Research on Post processing for Five-axis Machining Tool Based on Edgecam. Machine Tool & Hydraulics 42(20):4-6
7. Qiaomei Hao, Jie Jiang (2015) The customization and simulation about the double pendulum station of five-axis post-processing based on MasterCAM. Manufacturing Technology & Machine Tool (4):176-179
8. Yu, DY, Ding, Z. (2019) Post-processing algorithm of a five-axis machine tool with dual rotary tables based on the TCS method. Int J Adv Manuf Technol 102, 3937–3944
9. Xiuxiu Huang, Xiaoping Hu, Baohua Yu, et al (2015) Ultrasonic cutting mechanism of Nomex honeycomb composites based on fracture mechanics. Journal of Mechanical Engineering 51(23): 205-212
10. Haofeng Yu, Xiaoping Hu, Liyang Kong, Baohua Yu (2019) Process path planning based on efficiency model for ultrasonic cutting curved surface of honeycomb composite parts. Advances in Mechanical Engineering 11(10): 1-11

Figures

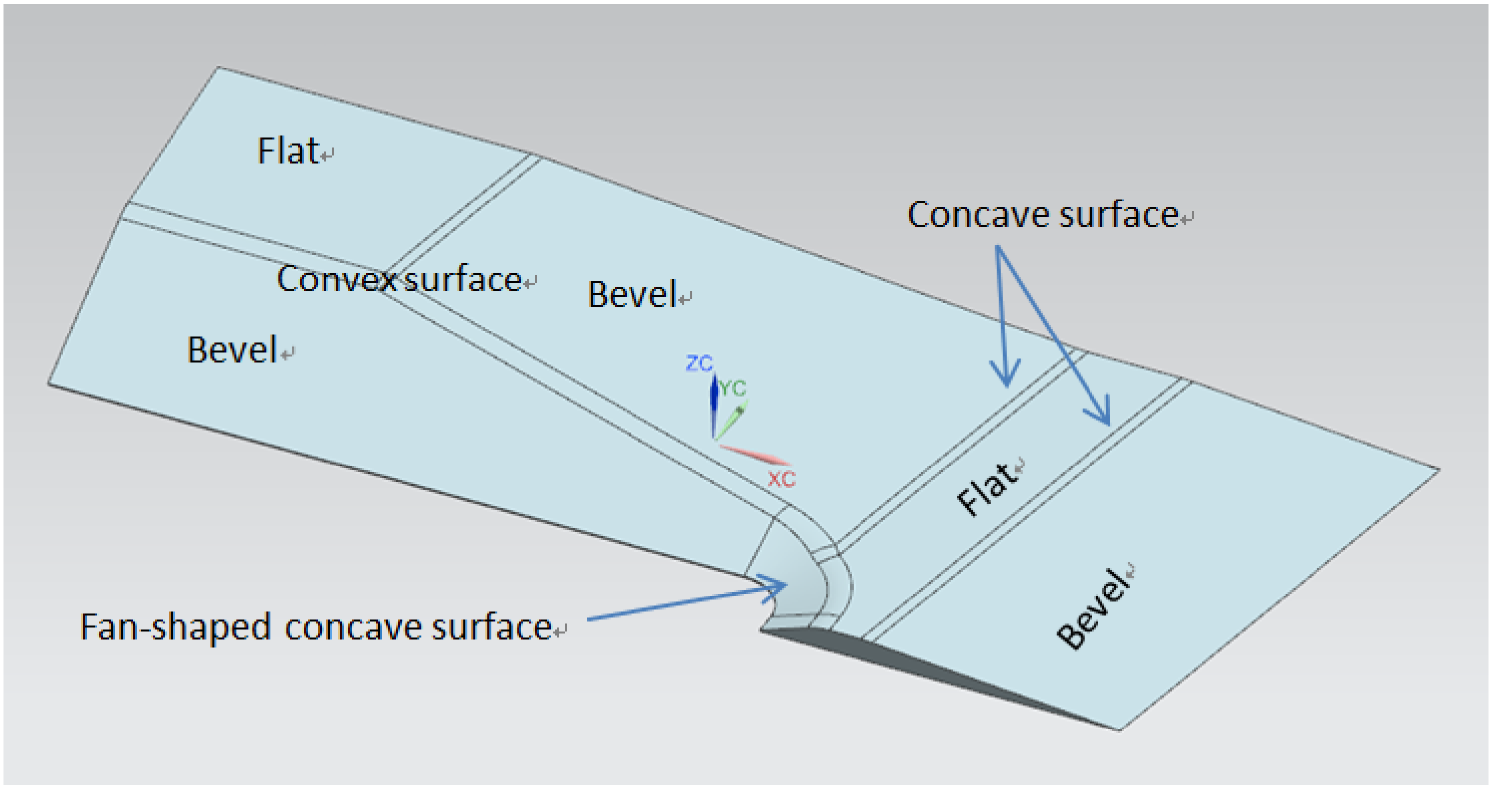

Figure 1

"V" shaped process for rough machining

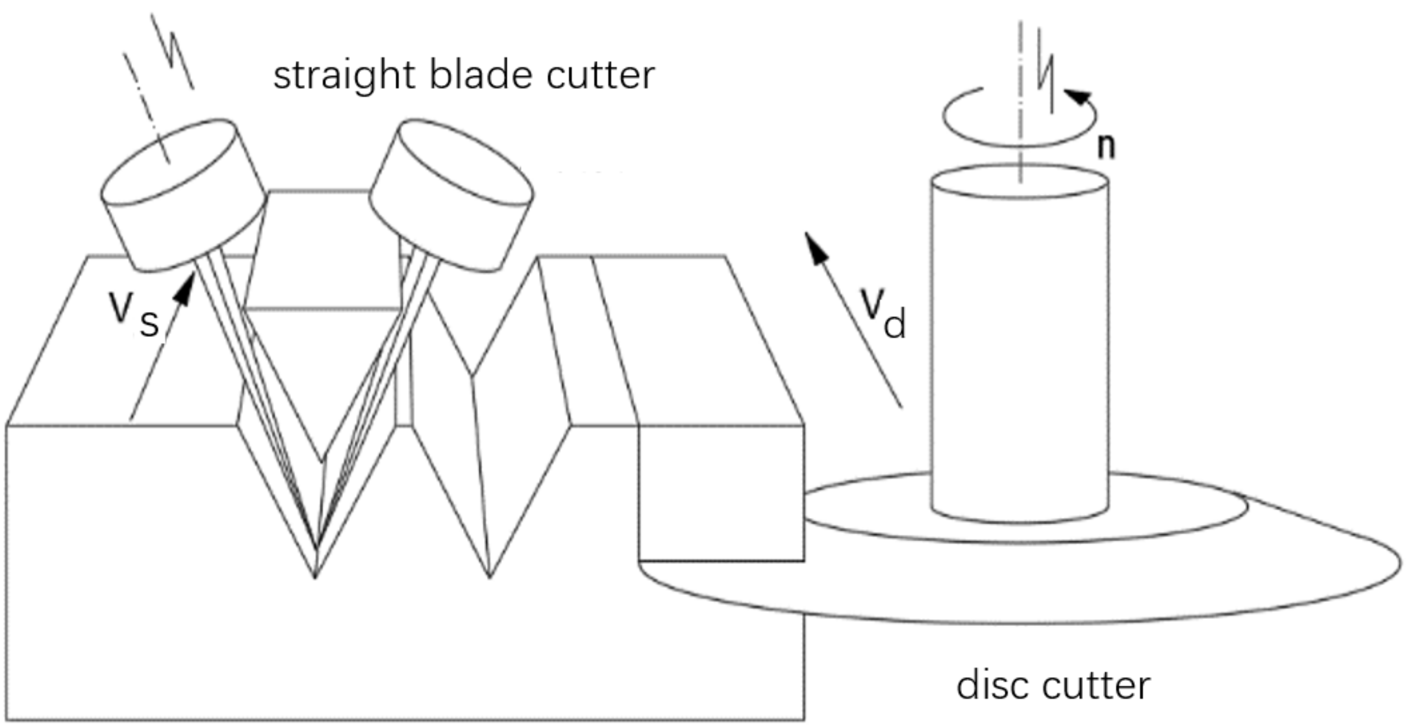

Figure 2

ultrasonic straight blade cutter and disc cutter

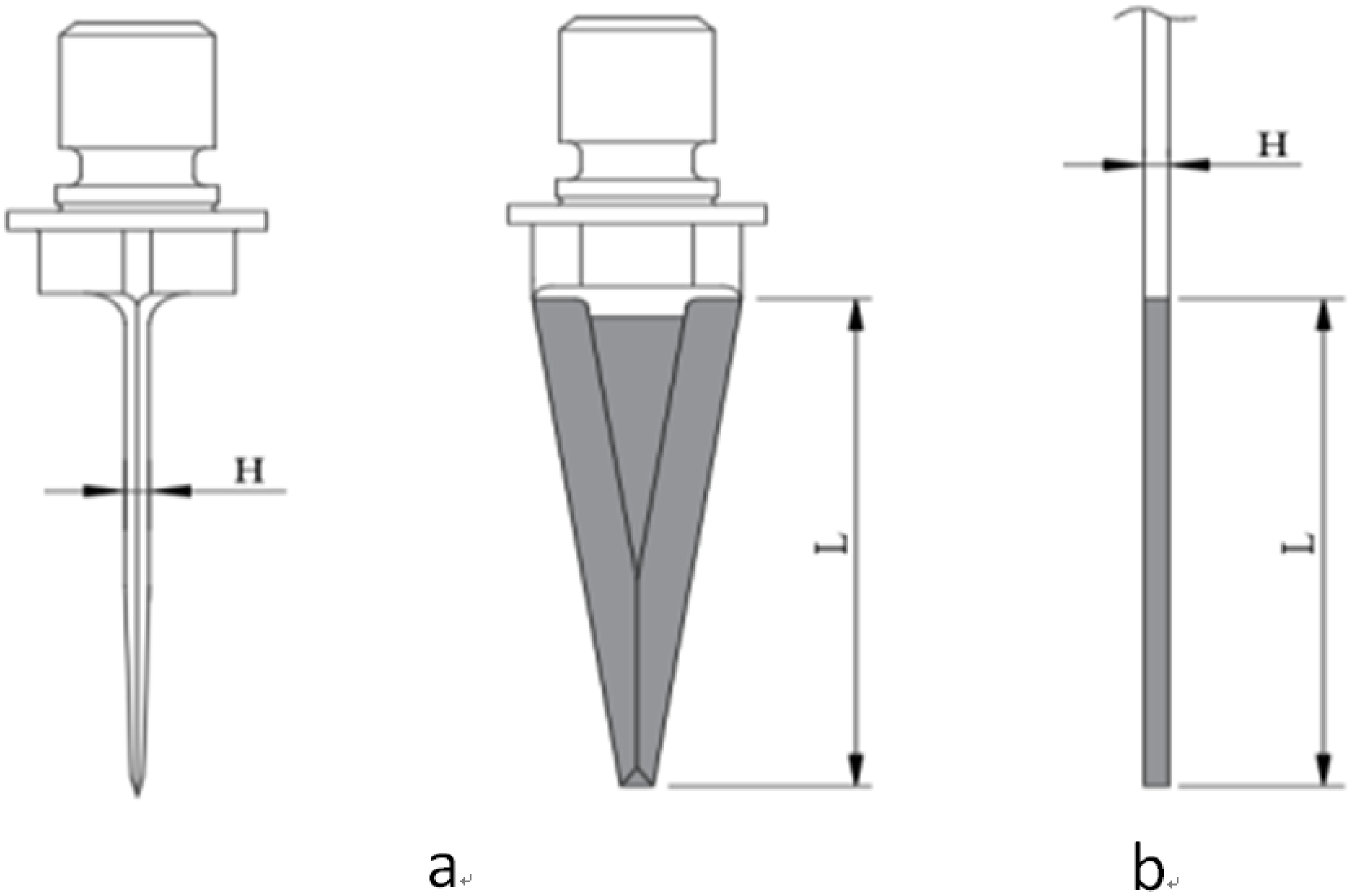

Figure 3

equivalent replace ultrasonic straight blade cutter (a. Straight blade cutter b. cylinder milling tool)

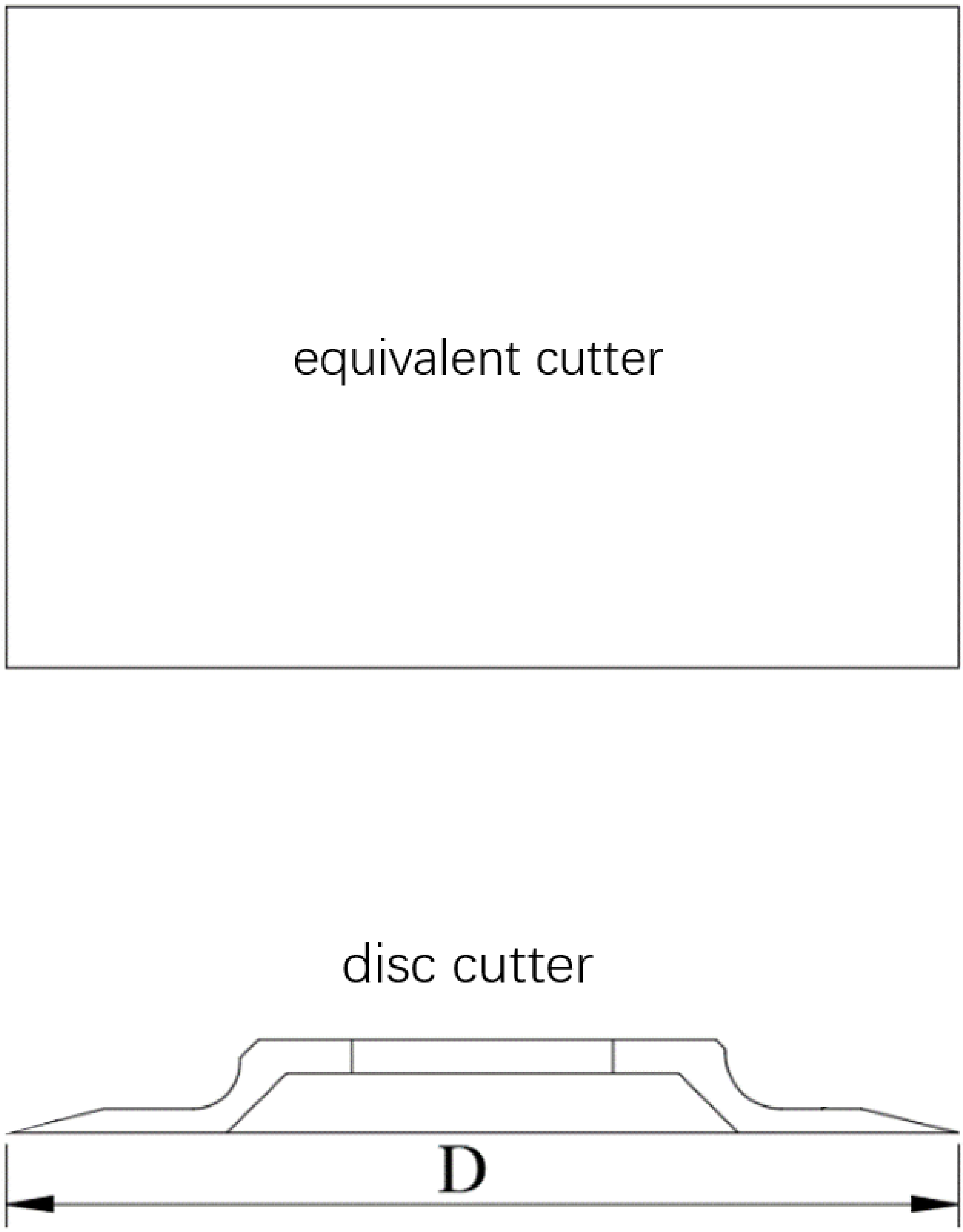

Figure 4

equivalent replace ultrasonic disc cutter

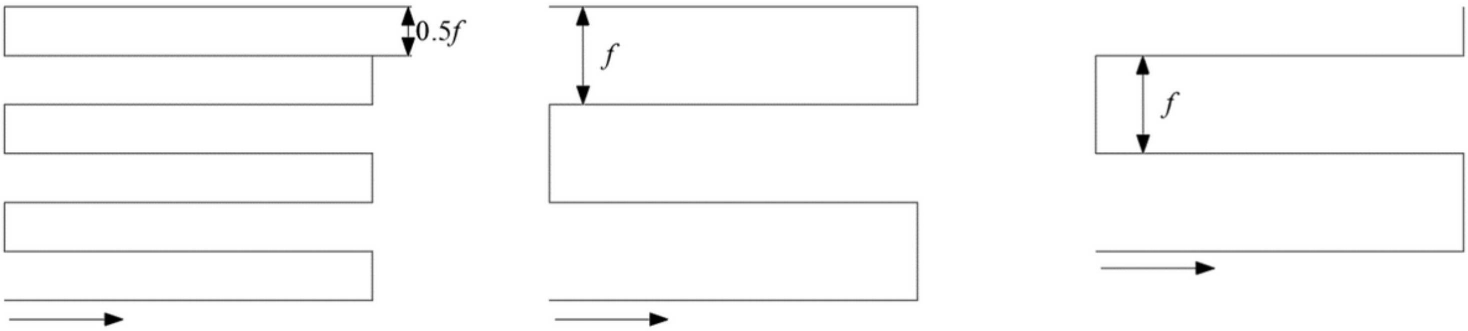

Figure 5

Sketch of tool path deletion 1 (a. Before deletion b.the odd-level toolpath after deletion c.the even-level toolpath after deletion)

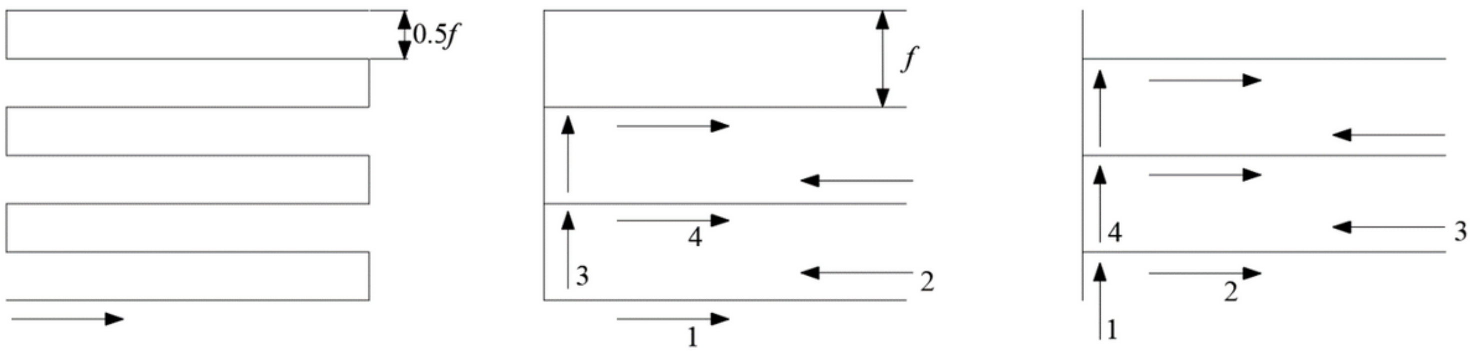

Figure 6

Sketch of tool path deletion 2 (a. Before deletion b.the odd-level toolpath after deletion c.the even-level toolpath after deletion)

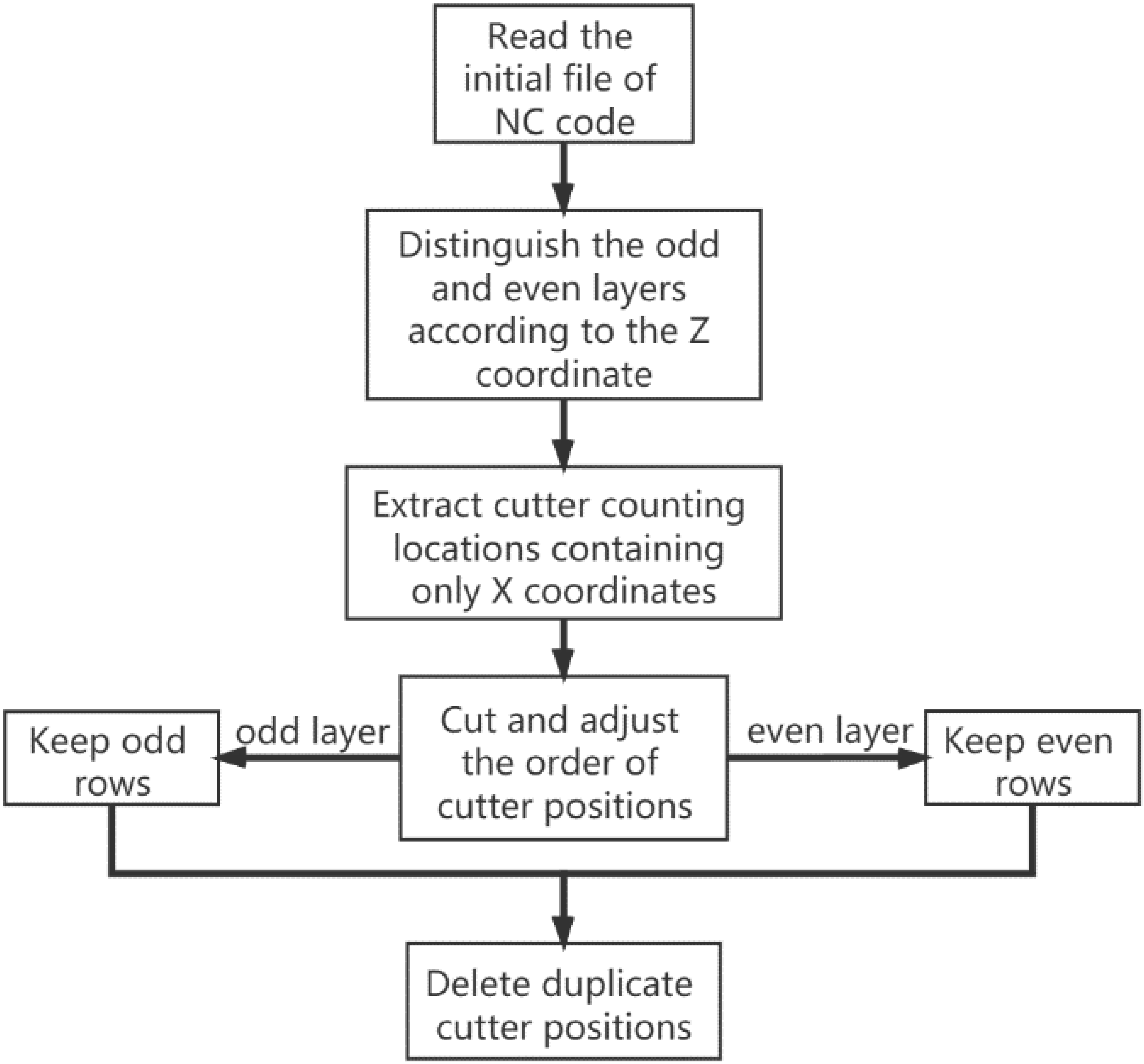

Figure 7

The route of reorganizing the sequence of CL

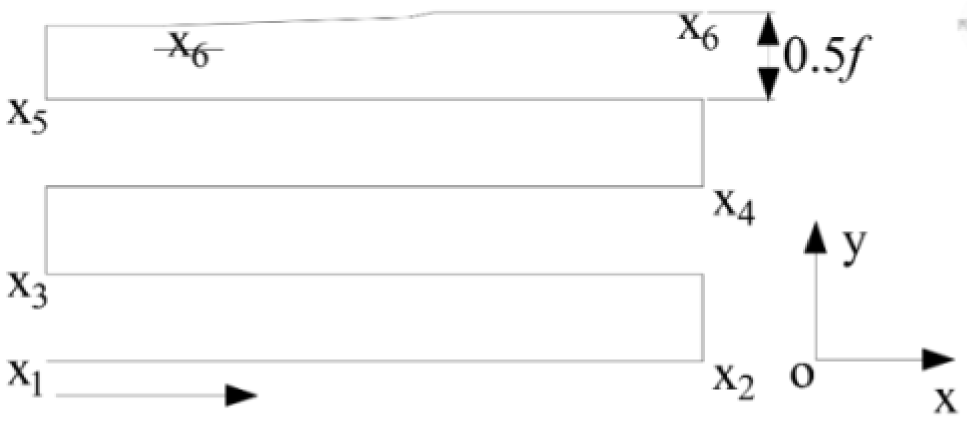

Figure 8

the selection rule of the CCL

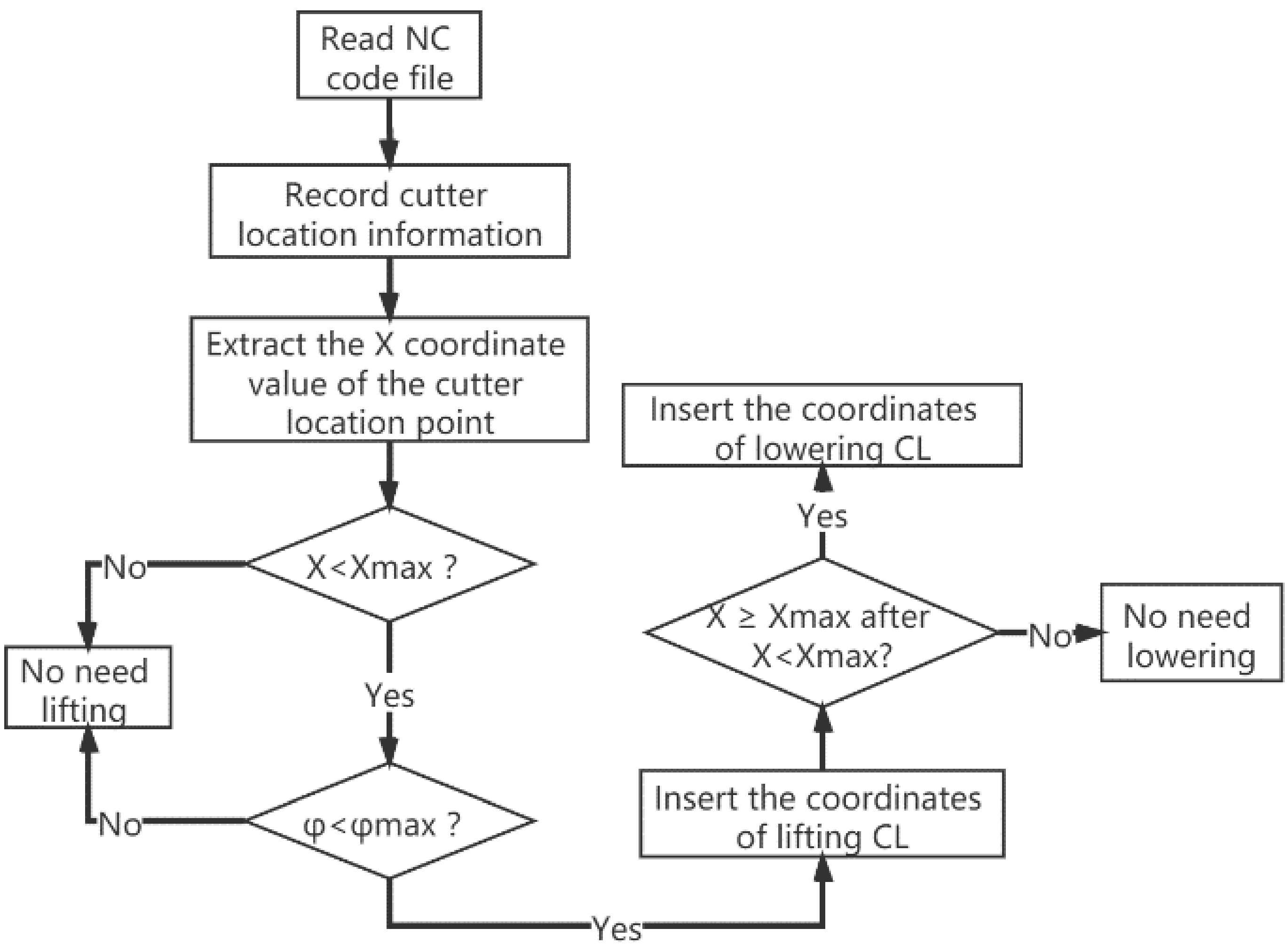

Figure 9

The route of lifting and lowering

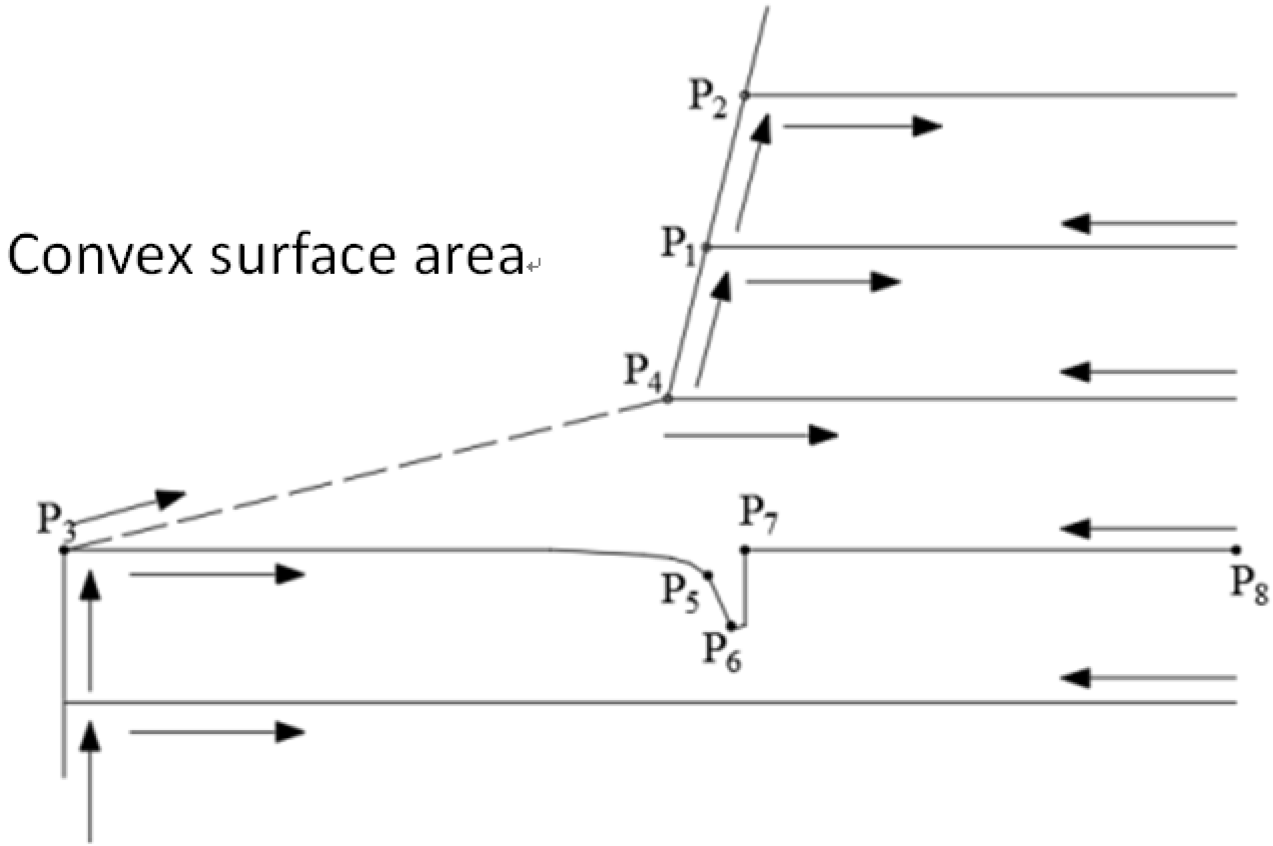

Figure 10

“V” shape machining tool lifting

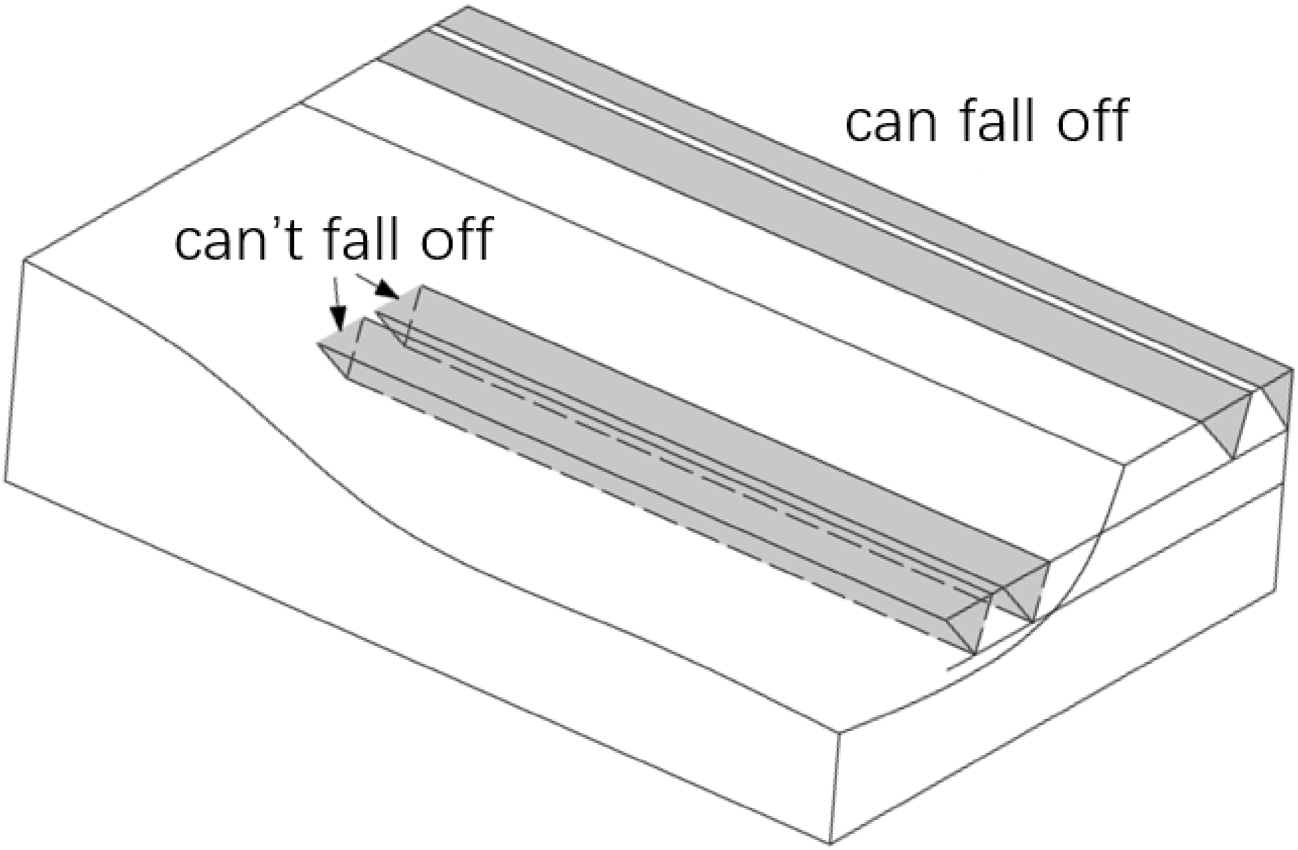

Figure 11

"V" machining process chip breaking

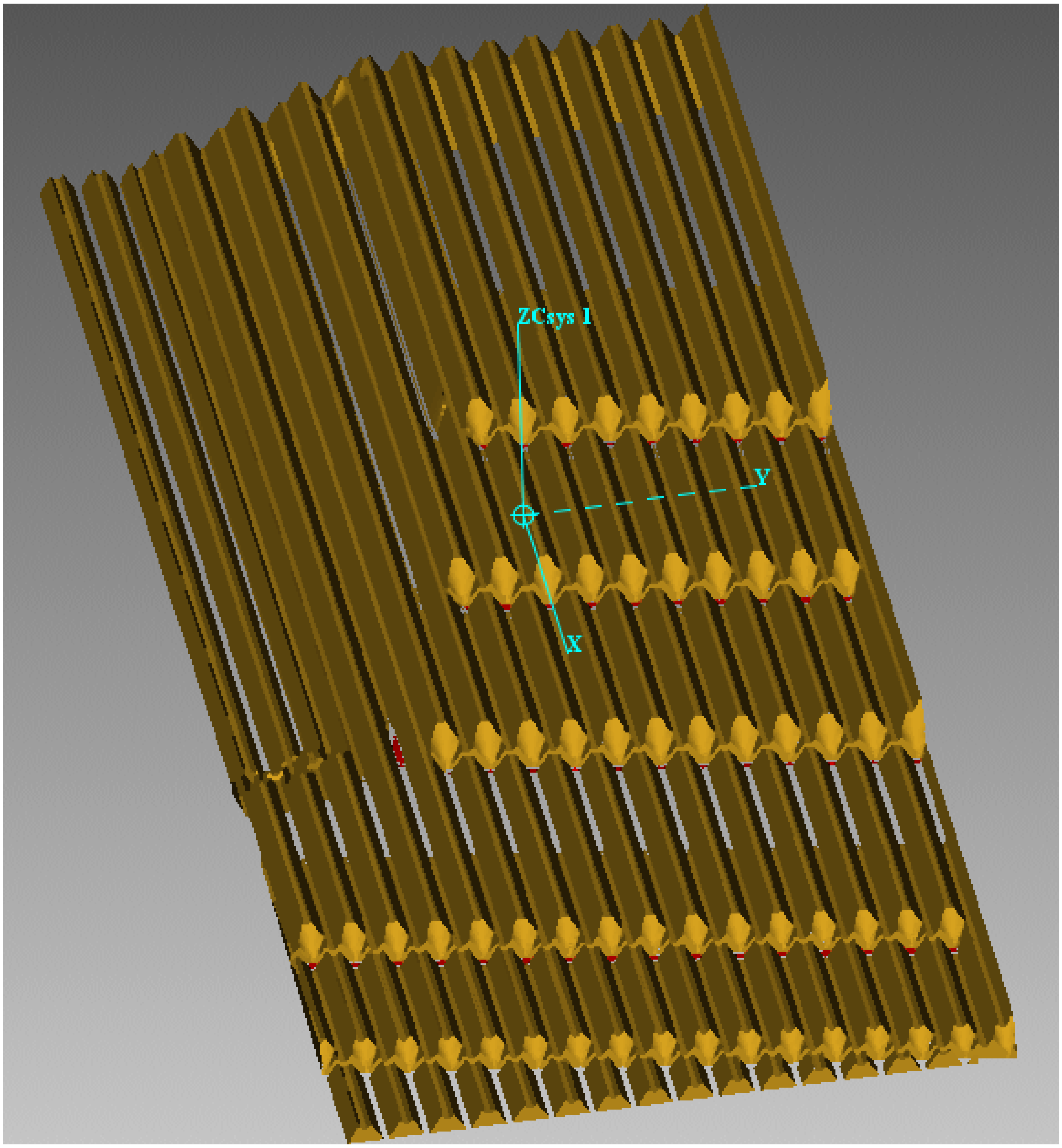

Figure 12

Rough machining residual solid model

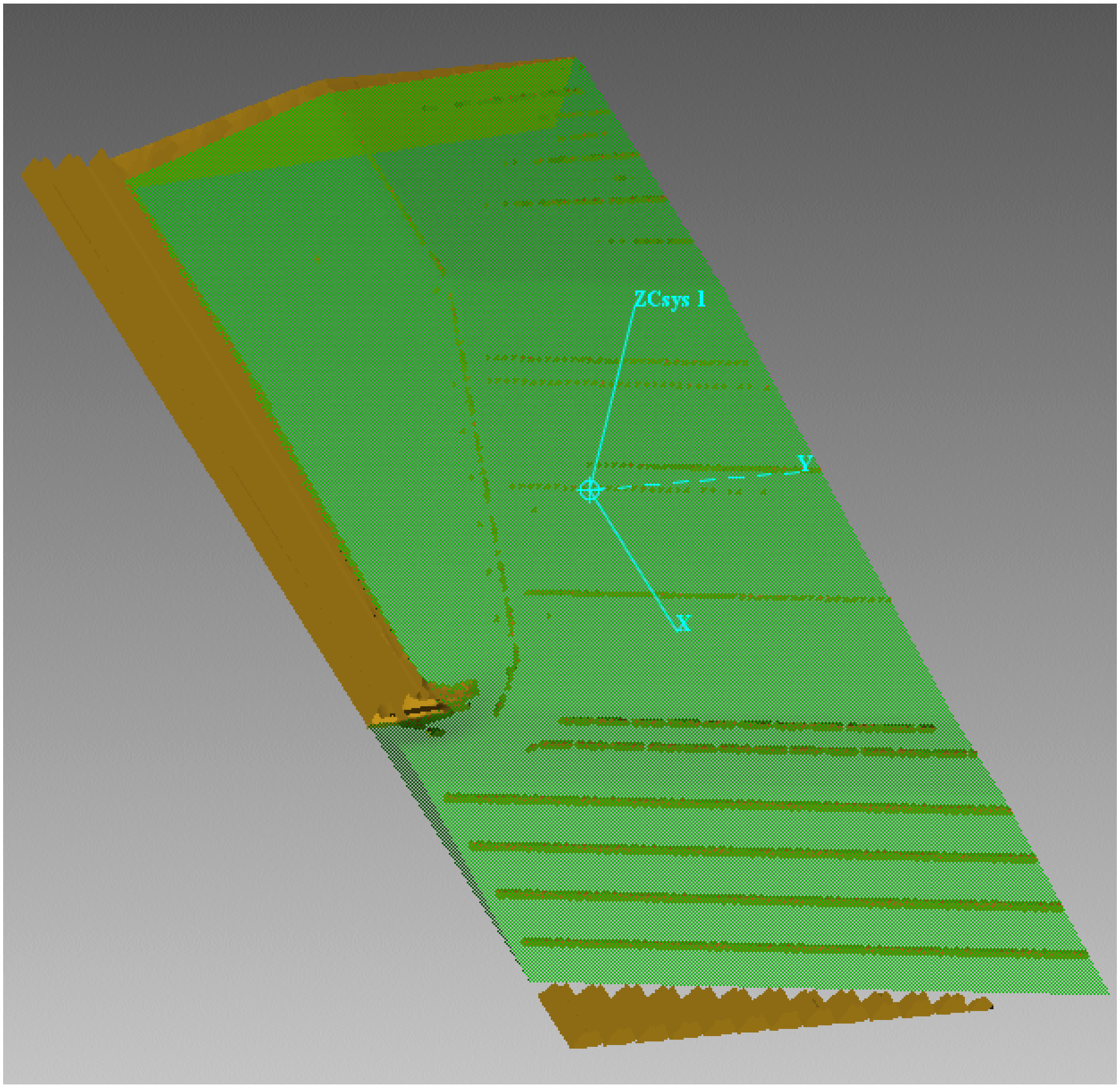

Figure 13

Comparison model of finishing residual entities and case parts