TOOL PATH GENERATION FOR FREE-FORM SURFACES MACHINING IN CNC MACHINE-TOOLS

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Abstract. *This work deals with the generation of toolpath of free form surfaces machining in CNC machine-tools with the use of automatically selected cutting tools. The method consists on the segmentation of the machining in the rough, carried through in cutting plans, and finishing, carried through in equidistant trajectories to the surface of the part. The form of the tools are adjusted to the considered stages and the cutting conditions are defined in function of the limits of the available tools, searching a lesser machining time. The systematization of these stages allows the attainment of conditions optimized for the accomplishment of geometry complex parts machining. The partial results demonstrate the importance and functionality of the considered method, as well as indicate the continuity of this study.*

Keywords*: tool path generation, CNC machining, free-form surfaces*

1. Introduction

The use of CNC machines has brought advantages larger than conventional machines, mainly in machining process of complex surfaces. Complex surfaces, also known as free-form surfaces have been widely used in the manufacturing industry, especially in recent years. Many times the molds used in the machining of several parts and consuming products have complex surfaces in their shapes. Due to irregular curvatures, the parts of complex surfaces are difficult to be machined, and sometimes, CNC program applied to control the machine can spend too much time to be made. Nowadays, with technological advance and the actual computational systems (CAD – Computer Aided Design and CAM – Computer Aided Manufacturing) have been indispensable added the others database systems, projects management and process planning.

In the manufacturing industry, the production cost of a part depends largely on the part's machining time. The machining parameters, such as machining planes and cutters are typically selected to reduce machining time end to prolong tool life. The methods developed tend to minimize the total machining time and the number of tool changes. Any reduction in the machining time can directly translated into reduction of production cost. Therefore, it is important to manufacturing engineers and process planers.

2. Free-form surfaces machining

The free-form surfaces, represented through parametric surfaces are obtained by the use of bi-cubical polynomials. Bézier, Catmull, Coons, Hermite, etc. (FOLEY, 1990), are examples of free-form surfaces and each one of them has a specific polynomial. Due to the variation of the coefficients and control points, it would be easier to obtain the varied surfaces. For example, the description of surfaces for Bézier curves is obtained through a product, having resulted the following equation:

$$P(u,v) = \sum_{i=0}^{n} \sum_{j=0}^{m} P_{i,j}\, B_{i,n}(u)\, B_{j,m}(v) \qquad (1)$$

which two similar functions of blending $B(u)$ and $B(v)$ are used, one for each parameter u and v. The Figure 1 demonstrates a free-form surface generated through the Bézier parametric form.

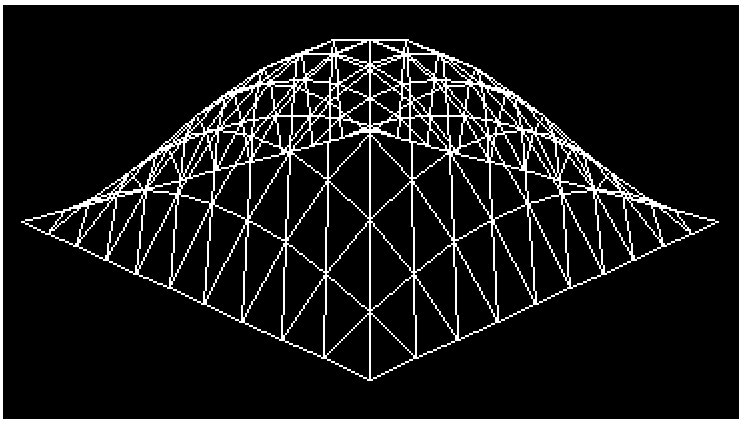

Figure 1. Bézier's Surface.

After the part's design has been done, a sequence of operations needs to be determined to transform the raw material into the final product. The machining of free-form surfaces can be divided into two different phases, that consists of the roughing and finishing process. Roughing is to remove the excess of material from the raw stock leaving a surface close to the final desirable surface. While finishing is to remove residual material along the surface after roughing is applied and it gives a part's final form. According to Chen et al (1998), generally the removal volume in roughing is five to ten times the removal volume in finishing. Thus, the reduction in roughing time can considerably increase productivity, which leads to the lower manufacturing cost. Therefore, the machining efficiency of roughing becomes the primary objective in CNC machining.

Roughing process can be made dividing the cavity into several hunting planes perpendicular of the tool axis and consists of a series of 2.5-D pocketing. They can be machined efficiently with a flat end-mill cutter. Roughing objective is to leave a "light material" close to the surface, such as the parts to be machined with just one step tool on finishing process. The cutting plans distance in roughing is typically less than half diameter of the finishing cutter. (OLIVEIRA, 2003)

3. Optimization of the free-form surfaces machining

In order to optimize the rough process in the manufacture of complex surfaces, Chen *et al* (1998), considered the use of two methods, one using the integer programming and another one the dynamic programming. In the planning process, the information of manufacture, such as the geometric form of a manufacture region, available cutting tools, volume to be removed, estimated machining time, are important for the generation of a good process planning and to facilitate the planning activities. These information of manufacture are typically not available clearly in the drawing or project. Especially in free form surfaces machining, the restrictions of manufacture formed by complex geometric forms become extremely important. The authors consider that the restrictions of manufacture are extracted firstly in order to automatizing the selection of cutting tools and manufacture plans. In order to extract the manufacture geometric restrictions, a series of cutting plans, perpendiculars to the tool, and with a fixed distance between two adjacent plans are used to intercept the complex surface desired. The contour of the intersection between the surface and the cutting plans is obtained by methods developed in previous works. (OLIVEIRA & SILVA, 2004)

The contours found through the intersection of the cutting plans with the surface are different for each plan. Consequently, the tools found for the adjacent cutting plans can't be the same. The geometry of the border or contour limit of the cutting plan restricts the size of the cutting tool that can be used for the manufacture "without" violating the surface. In the manufacture of the part, the necessary tool to move itself inside the limits of the pocket, to remove the material of the surface and to prevent the cut exceeds the surface. Therefore, a extration model of the geometric limits, to determine the tool, or a set of viable cutting tools for each cutting plan generated is used. These cutting plans are numbered from the bottom to the top of the pocket. The accurate cutting plan used in the rough operation, is not necessarily in the same position of the cutting plans generated before. The cutting plans initially determined can be merging with adjacent plans if it does not have restrictions of the tool such as the diameter and the maximum cutting depth allowed.

Summarizing, the process plan is carried through in two phases. The first phase is given by the arbitrary determination of cutting plans series used to extract the manufacture geometric restrictions, and to identify in the available tools all the viable cutting tools for each cutting plan. The tools & plans of manufacture selection are based in the geometric form of a manufacture region. Of this form, one or more tools that satisfy the countours geometric restrictions are found for each plan and send for a data base where tools information are stored. For each cutting plan, a definition of the tools and its corresponding costs of manufacture are evaluated, based in the machining time for each cutting plan with its respective tool, which can be calculated. The second phase is for to optimize tools selection and determination of the manufacture plan. To improve the productivity of the manufacture, the cutting tools are selected of a database obtained in the previous phase. The tools selection can be optimized by fusing of the adjacent cutting plans to minimize the total machining time reducing, in this way, the manufacture costs. The optimization model is then used to optimization of tools selection and determination of the manufacture plan.

4. Cutting Data

For each machining situation, considering part piece and tool information can be defined cutting conditions associating with the expectancy life of the tool. Thus, the work situation related with the registered cutting conditions in literature must be analyzed with the available cutting data in tools catalogues and be adjusted on the theory of machining. For example, the supplier of a tool recommends its use for some types of parts materials and offers an orientation on values of cut speed, advance and depth, that can be used directly or adapted with relation to the special characteristics from one determined machining operation (if roughing or finishing, for example) or same considering possibilities of the machine-tool in question. Then, the correct use of these available data is necessary, as of Table 1.

Table 1. Cutting data

Diameter (mm)	Spindle (rpm)	Feed (mm/min)	Max Cutting Depth (mm)
4	5200	420	2
6	3700	420	2
8	2800	420	3
10	2400	410	4
16	1600	410	6
20	1500	600	8

Font: Mitsubishi Carbide

5. The approach proposed

As demonstrated in this study it is presented in Figure 2, a free-form pocket modeled using a Bezier surface with 16 points of control, with depth of 80 millimeters. In this figure, two cutting plans for illustration are designated.

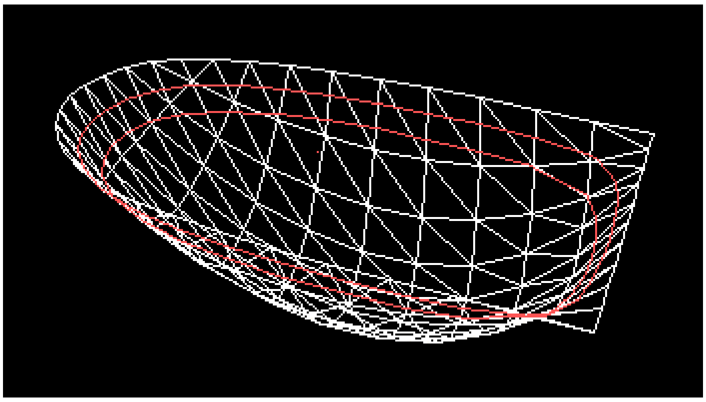

Figure 2. Free-form surface example.

For the generation of the cutting plans, we use as parameter, in the distance between the plans equally the maximum cutting depth recommended for the tool of lesser available diameter. Thus, according to the data of Table 1 in the distance between adjacent plans were 2 mm and had been generated 39 plans of cut. These plans had been generated leaving the bottom of the pocket until its top and numbered following this sequence. For each cutting plan generated its respective intersections with the surface of the pocket had been found. The intersection of each plan with the pocket surface results in a plain geometric figure represented by a closed contour, determining the area and the limits of the tools movement during the rough.

Table 2. Total machining time with tools selected

Cutting plans	Tool	Max depth of cut (mm)	Merge do cutting plans	Tool	Depth of cut (mm)	Machining time (s)	Machining time of each tool (s)	Total machining time (s)
39	D20	4,0	21	D20	2,0	**188,7**	**1695,0**	1713,4
38	D20	4,0	20	D20	4,0	**184,1**		
37	D20	4,0						
36	D20	4,0	19	D20	4,0	**178,0**		
35	D20	4,0						
34	D20	4,0	18	D20	4,0	**155,1**		
33	D20	4,0						
32	D20	4,0	17	D20	4,0	**150,1**		
31	D20	4,0						
30	D20	4,0	16	D20	4,0	**128,7**		
29	D20	4,0						
28	D20	4,0	15	D20	4,0	**121,1**		
27	D20	4,0						
26	D20	4,0	14	D20	4,0	**117,8**		
25	D20	4,0						
24	D20	4,0	13	D20	4,0	**98,7**		
23	D20	4,0						
22	D20	4,0	12	D20	4,0	**93,8**		
21	D20	4,0						
20	D20	4,0	11	D20	4,0	**87,9**		
19	D20	4,0						
18	D20	4,0	10	D20	4,0	**37,9**		
17	D20	4,0						
16	D20	4,0	9	D20	4,0	**34,4**		
15	D20	4,0						
14	D20	4,0	8	D20	4,0	**28,7**		
13	D20	4,0						
12	D20	4,0	7	D20	4,0	**26,5**		
11	D20	4,0						
10	D20	4,0	6	D20	4,0	**22,0**		
9	D20	4,0						
8	D20	4,0	5	D20	4,0	**17,9**		
7	D20	4,0						
6	D20	4,0	4	D20	4,0	**16,2**		
5	D20	4,0						
4	D20	4,0	3	D20	4,0	**7,4**		
3	D20	4,0						
2	D16	3,0	2	D16	2,0	**10,4**	**10,4**	
1	D4	2,0	1	D4	2,0	**8,0**	**8,0**	

These geometric information had been stored in an data base and used for the generation of tool path in each plan. The strategy of tools movement used for the rough was the zigzag. The lengths of cut for each plan had been found, with all viable tools, that satisfy the restrictions of the contour. With the information of cut lengths and the recommended feed values found in Table 1 it was possible to calculate the respective machining times. These information had been stored in an archive text and repassed for a table.

The following step was the determination of the manufacture plan. In this phase we use the data of the table generated in the previous phase. For determination of the manufacture plan it was analyzed the possibility of fusing adjacent cutting plans, with the objective to minimize the number of machining plans and consequently to minimize the machining time. In this analysis it must be considered the factors that determine the maximum cutting depth for the pocket in question. They are: the maximum cutting depth the tool can support and the maximum amount of material that can be left to effect the passing finishing in an only one. Thus the adjacent fusing of one or more cutting plans does not have to exceed the maximum cutting depth allowed. For the considered example the tool used for finishing was a of half-spherical extremity tool with 10 mm of diameter and with 5 mm of maximum cutting depth. Observing this parameter, is possible to effect the fusing "of up to two" adjacent plans, since it does not exceed the maximum cutting depth recommended for the tool in question. The results of this fusing are presented in Table 2.

It was observed that in the plans of cut 1 and 2 one had restrictions that not allowed the use of tools with diameters bigger than 4 and 16 millimeters respectively. Obviously that modifying the form of the pocket and increasing the surfaces complexity, the restrictions could be bigger or it would have more restrictions. From the cutting plan, it was possible to use a tool with a diameter with 20 millimeters, the bigest diameter tool we had available. In the pocket machining, a lesser machining time is waited when it can be used tools with bigger diameters.

It is still perceived that when it was transferred to be used, the tool with 20 milimeters of diameter were carried through the junction of two adjacent cutting plans, reducing the number of effective cutting plans, that passed of 39 for 21. In the machining process, the execution of the operation is carried through its inverse order of plans numerations. It is initiated machining on plan 21, later on plan 20 and thus successively until plan 1, finishing the rough operation of this pocket.

6. Conclusion

This work is part of a bigger project. The obtained results are inside their limits. The next step is to extend the choice of the tools and the number the generated cutting plans beyond the parameters used for the fusing of two or more adjacents plans, searching for a bigger optimization level for this process.

7. References

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