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Tool-path Scheduling for Free-form Surface Based on MasterCAM

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Abstract. The tool-path generating methods of roughing and finishing provided by MasterCAM were systematically analyzed including their features and applications. Then a blade with freeform surface milled by different tool-paths was simulated. According to the comparison of simulation effects and information, the flow-line tool-path was proposed to be optimal for machining blade with freeform surface. Finally, the blade was finished with optimal tool-path using a 3-axis NC milling machine.

Introduction

Freeform surface as a kind of complex surface frequently appears in the various components in the automobile, aviation and aerospace etc industries[1]. With improving of their quality demands, CNC technology has become one of the most important manufacturing technologies. MasterCAM is becoming the preferred CAD/CAM software because of its powerful functions such as rich 3D surface modeling and convenient NC programming[2]. The software provides varieties of tool-path generating methods. What's more, each method has its own characteristics and generates different tool-paths which suit for different surfaces. Little literature has in-depth and systematic analysis about how to generate optimal tool-path. Confusing about tool-path scheduling makes engineers hard to choose proper method, so thoroughly researching on common roughing and finishing tool-paths, optimizing the tool-path based on the characteristics of surface can not only improve machining efficiency and accuracy, but also reduce the cost of manufacturing to a great extent. For these considerations, a blade with freeform surface was modeled and machined with each available tool-path to compare their machining effects based on the analysis of various tool-path scheduling methods. By these researches, the understanding of the tool-path scheduling is more profound than ever and the suitable tool-path was scheduled for the blade, which will provide references for engineers to improve machining quality and efficiency.

Introduction of common tool-path scheduling of MasterCAM

Rough machining is mainly used to remove most of the extra material which places emphasis on machining efficiency. However the finish machining is used to cut residual materials to meet technical requirements which pays more attention to the machining quality[3]. Common tool-path scheduling methods of MasterCAM are analyzed and shown in Tab.1.

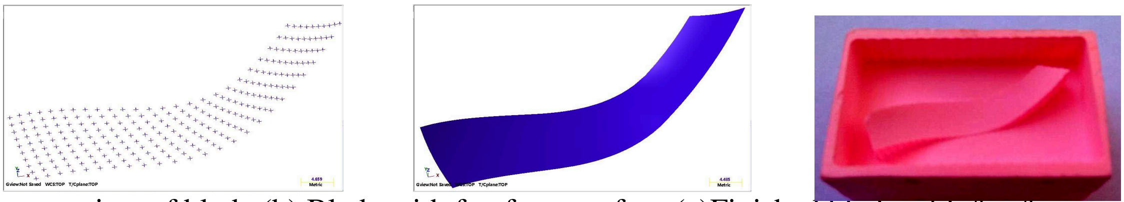
Tab.1. Introduction of common tool-path scheduling

Tool-path	Principle	Feature and application
Parallel	Generate footpaths paralleling to the X axis with a certain angle	An effective and common method; Grooves are more obvious on the steep surface; Retract more frequently when machining complex surface.
Radial	Cut from a center point to outward; Create cuts like the spokes of a wheel	Apply to round and center symmetry space; Non-uniform machining precision and low machining efficiency.
Flow-line	Follow the shape and direction of surfaces to create a smooth and flowing footpaths	Calculation of the paths is complicated; Suit for complex and streamline surface instead of simple surface

Contour	Product footpaths along the contour of the surface; Paths always against surface	Effective; Apply to parts with steep walls; The quality of flat surface processing is poor; Can't be used to remove too excess material
Pocket	Rough the outside of the part and the pocket on the front of the part by some layered footpaths	Effective; Preferred cutting method for many roughing tools
Parallel-Steep	Create parallel footpaths on surface falling between two bigger slope angles	Usually be used after a finish parallel tool-path to machining surfaces in high angle; Applicable range is small
Shallow	Create parallel footpaths on surfaces that fall between two smaller slope angles contrasts with parallel-steep footpaths	Applicable range is small
Constant Scallop	Create a consistent scallop height footpaths over the whole surface	The machining effect of regular surface is great; With long NC code and low efficiency

Examples of machining a blade with freeform surface

Geometric modeling. The 3D modeling is based on data points which are obtained through the wood-line map and axial projection map. First, discrete points were drawn in MasterCAM; then curves and surface were generated step-by-step[4]. The figures of discrete points (25*10) of blade with freeform surface and the surface are shown in Fig.1-(a) and Fig.1- (b). The finished blade with freeform surface is show in Fig.1-(c).



(a) Discrete points of blade (b) Blade with freeform surface (c)Finished blade with freeform surface

Fig.1. Modeling of a blade with freeform surface

Roughing. Radial tool-path is obviously not suitable for this surface which has slender shape and high and changeful curvature. Furthermore, tool-path of contour can't be used to cut a large amount of blank material. So the tool-paths of pocket, flow-line and parallel were scheduled to compare the effects of their simulation. The general roughing parameters are set to the same values to ensure the results are comparable, which are shown in Tab.2.

Tab.2. Roughing parameters

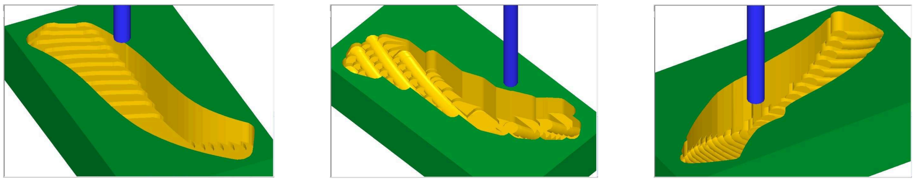
Tool	Feed rate [mm/min]	Spindle speed [r/min]	Plunge rate [mm/min]	Retract rate [mm/min]	Retract [mm]	Feed plane [mm]	Stock to on drive [mm]	Total tolerance [mm]	Max. Stover [mm]
Φ3End mill flat	400	2500	300	300	15	5	0.2	0.05	1

Note: Stover distance of pocket and parallel is 2.1 [mm]; Step-over distance of flow-line is 2.1[mm]; Other special parameters according to the optimal design.

The effects of rough machining simulation are shown in Tab.3 and Fig.2.

Tab.3. Information of rough machining simulation

Machining methods	NC code [KB]	simulation graphics	Path Length Feed[mm]	Path Length Rapid[mm]	Cycle Time	efficiency
Pocket	272.4	2-a	3427.029	348.816	8m:39.22s	③
Parallel	71.6	2-b	2348.671	1517.638	6m:09.24s	①
Flow-line	159.41	2-c	2502.67	925.408	7m:33.62s	②



(a) Rough pocket (b) Rough parallel c) Rough flowline

Fig.2 Simulation of Roughing

Tab.3 and Fig.2 show that under the same condition of machining, rough pocket has better machining quality in the edge, but longer machining time than other two tool-paths; Rough parallel has higher efficiency but serious uneven step-like scallop height which will seriously impact the future finishing and even results in damages of tools and surface; Rough flow-line has comprehensive superiority both in quality and efficiency since flow-line tool-path follows the shape and direction of the surfaces and creates a smooth and flowing tool-path motion that make it to be right for machining freeform surface with flow characteristics.

Finishing. Finishing with finishing tool-paths of parallel, flow-line, contour and constant scallop were simulated. Finishing parameters were listed in Tab.4.

Tab.4. Finishing parameters

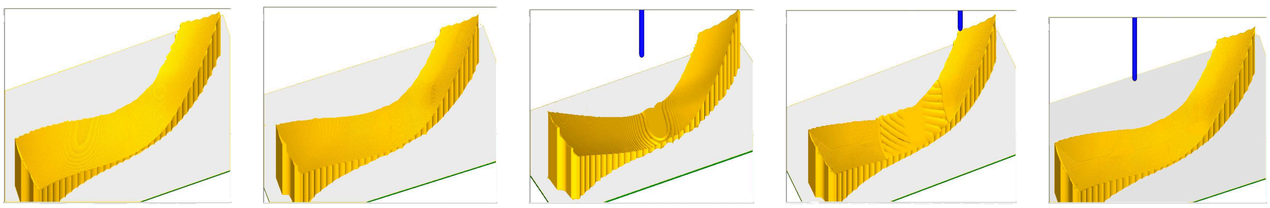
Tool	Feed rate [mm/min]	Spindle speed [r/min]	Plunge rate [mm/min]	Retract rate [mm/min]	Retract [mm]	Feed plane [mm]	Total tolerance [mm]
Φ1End mill sphere	450	3000	350	350	10	3	0.01

Note:The max stepover of finishing contour, parallel, constant scallop, shallow:0.2[mm]; The scallop height of flowline: 0.02[mm]

The effects of finish machining simulation are shown in Tab.5 and Fig.3.

Tab.5. Information of Finish machining simulation

Machining methods	NC [KB]	Simulation diagram	Feed Path Length [mm]	Rapid Path Length [mm]	Cycle Time	Efficiency	quality
Parallel	515.8	3-a	2539.828	454.349	5m43.68s	③	great
Flowline	258.8	3-b	2127.253	17.000	4m43.83s	①	perfect
Contour	517.6	3-d	2095.197	820.479	4m48.43s	②	bad
Constant Scallop	742.4	3-e	1703.711	63.03	3m47.69s	/	worst
Constant Scallop&Shallow	1131.7	3-f	2640.632	941.057	6m00.01s	④	good



(a) Finish Parallel (b) Finish Flow-line (c) Finish Contour (e)Constant Scallop (f) Constant Scallop+Shallow

Fig 3. Simulation graphics of finishing

Tab.5 and Fig.3 prove that the machining effects are distinctly different when machining with different tool-path scheduling. Concrete analyses are described.

Tool-path of finish contour has high processing efficiency but bad overall surface quality. The quality on both ends of steep curved surface is much better than the middle shallow. That indicates it is not reasonable to choose contour to plan tool-path when the surface is flat or exits shallow area. Tool-path of finish constant scallop has high residual ridge at the tool-paths corner and a large part of unprocessed in the middle of the surface. To solve this problem, shallow tool-path can be used to machine the unprocessed areas, with slope angle from 0 to 25º, and overlap paths were pruned by trimmed. The final simulation results are shown in Fig.3-(f) and Tab.5. Different tool-path scheduling methods combined can machine surface with many features. But problems such as path planning difficulty, processing surface roughness uneven should be considered. Tool-path of finish parallel has high efficiency and great overall quality. The processing quality of middle flat is better than that of end steep surface, which confirmed finish parallel tool-path applies to most surfaces, especially the flat one. Tool-path of finish flow-line is the most effective and efficient. All the analyses above show that the machining effects are best using rough flow-line and finish flow-line to schedule tool-paths for this blade.

Experiment. A machining experiment was conducted on Personal Portable CNC (PPCNC)[5] using the optimal tool-path scheduling proposed above. The working stroke of PPCNC is X*Y*Z=74*42*68mm; Blank material is epoxy tooling board, which size is 55*35*20mm. The finished blade with freeform surface is show in Fig.1-(c).

Conclusion

The principle and characteristics of common tool-path scheduling methods in MasterCAM were analyzed. Flow-line roughing combined with flow-line finishing tool-path is determined to be the optimal planning for machining blade with freeform surface which has been verified through software simulation and machining test. Scheduling optimal tool-path by mastering the principle and features of each tool-path, analyzing the characteristic of surface, can greatly improve the machining efficiency and quality.

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