

Research on Five-Axis Numerical Control Programming and Machining Technology of Micro Integral Impeller

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Abstract—Micro integral impeller is the key component of micro aero-engine, and its machining quality will directly affect the performance of micro-engine. Aiming at the narrow flow path of the tiny integral blade, the large distortion of the blade and the large ratio of free-form surface and divided into main and double blades, the five-axis NC machining method of the micro-integral impeller is studied in this paper. The research on the five-axis NC machining method of the micro-integrated impeller is carried out. Firstly, according to the structural characteristics of the micro integral impeller, the NC programming is carried out in Siemens NX software, and the obtained tool path is verified by 2D dynamic simulation and 3D dynamic simulation. Finally, the micro integral impeller is obtained through the milling test. There are no interference, overcutting, undercutting and other problems in the machining process. Thus, the correctness of the machining technology and machining method is verified.

Keywords-Micro Integral Impeller; NC Programming; Five-Axis Machining; Virtual Simulation

I. INTRODUCTION

Micro integral impeller is a typical part of micro aircraft propulsion unit, power generation device and auxiliary power plant, which has a wide range of applications in military and civil fields. It is a kind of parts with narrow twisted channel, semi-closed and thin-wall surface in complex space. So that is very difficult to design and process. As the core components of the propulsion device, power generation device and auxiliary power plant of the micro aircraft, the machining method, machining accuracy and machining surface quality of the micro integral impeller have a great influence on its final performance parameters, so it is of great significance to study the efficient and high quality machining method of the micro integral impeller.

Many universities and research institutes at home and abroad have carried out research on the processing of micro integral impellers, and various processing methods have also

been developed. The gas turbine laboratory of the Massachusetts Institute of Technology uses MEMS technology to process micro-turbines[2]. The rapid prototyping laboratory of Stanford University in the United States has used the technology of SDM technology combined with injection molding to manufacture a ceramic micro gas turbine rotor [3]. The stainless steel micro-turbine rotor is machined by electric spark machining technology in the University of Ruin, Belgium[4]. In addition, the university also machined the titanium alloy micro-impeller by the Cohen micro-milling machine[5]. Imperial College of Technology uses an innovative method of excimer laser processing of axially structured microturbine transducers on PMMA materials[6]. Seoul National University uses a PC-based five-axis micro-milling machine to machine micro-impellers on copper workpieces[7]. Tohoku university cooperated with some Japanese enterprises to develop micro-centrifugal impeller manufactured by five-axis micro-milling a five-axis micro-milling[8]. Harbin Institute of Technology used a micro-EDM milling to process complex curved metal micro-compressors, which are made of GH4169 high-temperature nickel alloy material[9], and use the engine rotor mold to produce tiny straight-wall impellers by extrusion molding[10].

Through the above paper, it is found that five-axis NC machining has advantages in the machining of micro integral impeller parts, so five-axis NC machining is used to process micro integral impeller and related research is carried out. Five-axis NC machining can not only reduce the clamping times to improve the machining accuracy, but also improve the machining efficiency. In this paper, the NC machining scheme of the micro integral impeller is formulated. The NC programming of the micro integral impeller is carried out by using Siemens NX software, and the 2D dynamic simulation verification and 3D dynamic simulation verification are conducted. Finally, the actual machining experiments are carried out to verify the correctness of the NC programming trajectory.

II. THE MODEL OF THE MICRO-INTEGRAL IMPELLER

The micro-integral impeller can be regarded as several main blades and splitter blades distributed on the hub along the circumference array of the impeller axis. Its main structure includes several parts, such as main blade, splitter blade, blade root rounded angle and hub. As shown in Fig. 1, the main blade is composed of the pressure surface, suction surface, leading edge and trailing edge. The pressure surface and suction surface are collectively referred to as the blade profile. When the impeller works, the blade edge facing the airflow is called the leading edge (also known as the air inlet edge), and the blade edge along the airflow is called the trailing edge (also known as the exhaust edge). The space between the pressure surface, the suction surface and the curved surface of the adjacent two blades is called a flow channel. In the micro-integral impeller, the intersecting part of the hub and the blade uses the transition method of fillet, commonly referred to as a fillet of the blade root (also known as the fillet transition surface), in order to ensure the smooth connection between the hub and the blade.

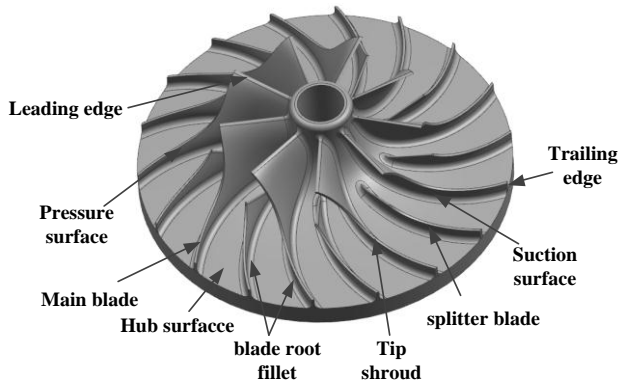


Figure 1. Geometric features of an impeller

In this paper, the blade surface of the micro-integral impeller is the free-form surface, with 18 blades, 9 main blades and 9 splitter blades, 32 mm in diameter and 9.9 mm in height. The thinnest blade is only 0.2 mm, the distance between adjacent main blades is 1.6932 mm, and the radius of root fillet is 0.5 mm. As shown in Fig. 2.

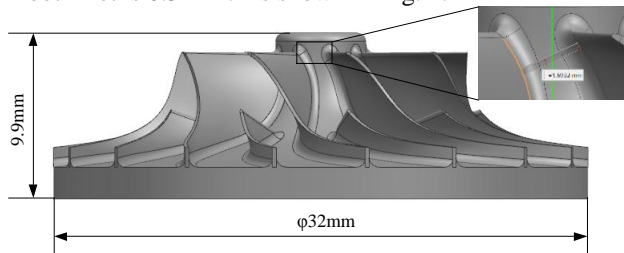


Figure 2. Structural dimensions of micro integral impeller

III. NUMERICAL CONTROL PROGRAMMING OF MICRO INTEGRAL IMPELLER

A. Siemens NX numerical control programming process

In Siemens NX, numerical control programming is carried out for each procedure of integral impeller processing. The steps of numerical control programming and processing are shown in Fig. 3.

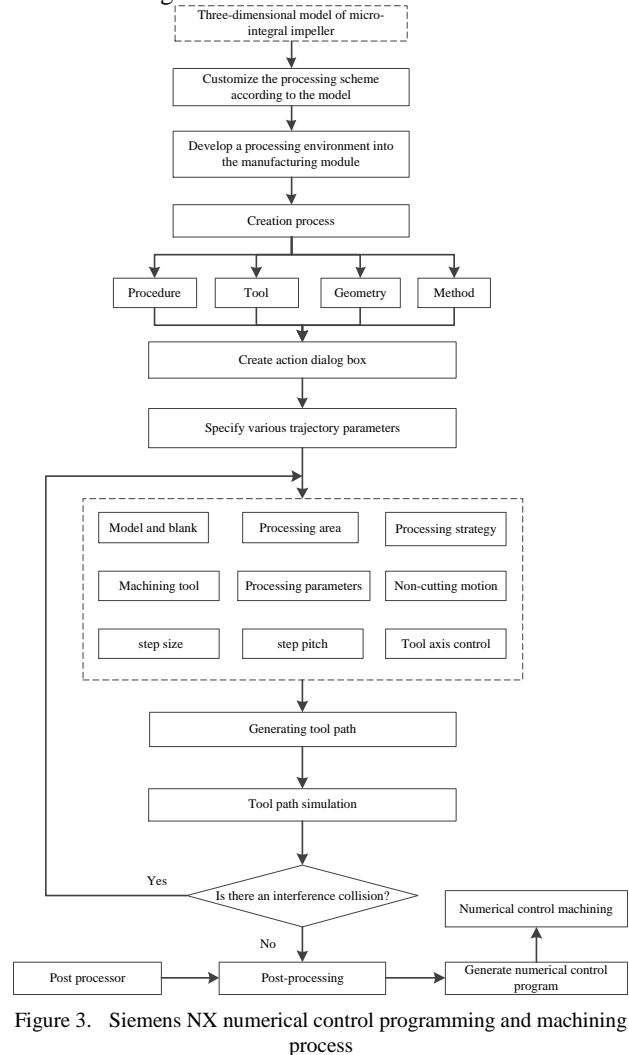


Figure 3. Siemens NX numerical control programming and machining process

B. Tool path planning based on Siemens NX

The micro integral impeller is a complex modeling part, and the tool path planning is completed by automatic programming software. In this paper, the machining module of Siemens NX is used to plan the tool path, and the special module "mill_multi_blade module" of impeller programming is used to program.

In this paper, 2D simulation and 3D dynamic simulation are combined to verify the generated tool path. And 3D simulation needs to consider the parameters such as the shape and size of the tool and fixture in machining, and can also set a variety of cutting parameters to simulate the real

machining process, check the correctness of the tool path, and ensure that the trajectory will not interfere and collide.

1) *Tool path planning for rough machining of impeller flow channel:* Rough machining is the first process of processing the blank, about 70% of the surplus is completed by rough machining in the whole processing process. The roughing process consumes a lot of processing time, and the surface quality and residual stress after rough machining will also affect the subsequent semi finishing process and the surface quality of semi finishing. Therefore, the efficient and reasonable planning of the roughing tool path of the micro impeller is of great significance in the actual machining process of the actual impeller.

In the aspect of machining parameters, the main purpose is to improve the material removal rate of impeller and to leave the machining allowance of 0.25mm for finishing machining. Considering that the cutting depth of thin-wall parts in impeller position can not be set too large, it is decided to adopt the cutting parameters of small cutting depth and large feed. In order to ensure the smooth progress of the machining process, the setting of the cutter axis vector direction is very important. The maximum tool inclination angle is 30° . The rough machining trajectory of the flow is shown in figure 4, and the "3D dynamic" simulation results of the rough flow path are shown in figure 5.

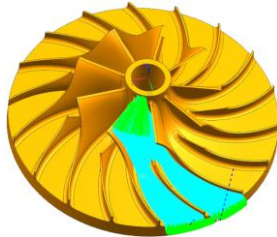


Figure 4. Impeller flow path rough tool path

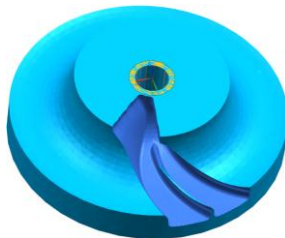


Figure 5. Rough flow path "3D dynamic" simulation results

2) *Impeller flow path finishing trajectory planning:* Since the micro-impeller structure is a double-flow structure, the opening of the flow passage is worse than that of the single-blade impeller. Therefore, in the finishing stage of the hub, it is necessary to select a ball-end milling cutter with a smaller cutter diameter to ensure the cutting precision. Avoid overcutting and collisions due to excessive tool diameter. The carbide tip milling cutter with a diameter of 1mm is used to cut the wheel from the trailing edge of the blade, and the hub is finished by reciprocating the knife along the flow path direction to the leading edge of the

blade. During the machining process, it is also necessary to adjust the angle of the cutter shaft according to the extending direction of the flow passage to avoid interference with the blade. Fig. 6 shows the finishing tool path of a single flow path. Fig. 7 shows the "3D dynamic" simulation result of the flow path finishing.

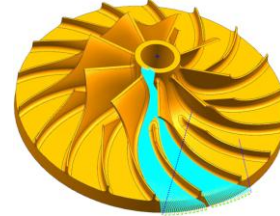


Figure 6. Impeller flow path finishing tool path

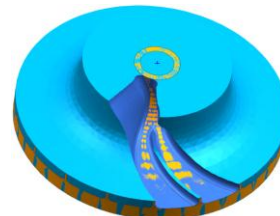


Figure 7. "3D dynamic" simulation results of flow path finishing

3) *Tool path planning for impeller blade finishing:*

The impeller blades studied in this paper include two types: main blades and split blades. Therefore, it is necessary to separately plan the two types of blades for finishing. And the blade is also the most important part of the tiny overall impeller machining, and its surface quality affects the overall performance of the impeller.

In the blade finishing stage, the thinnest part of the micro-integrated impeller blade is only 0.2mm, which is easy to generate vibration during machining and the blade machining error or even scrap due to the stiffness problem. Taking into account the machining accuracy of the blade, it is decided to use the point milling method to carry out the finishing process. The blade finishing tool path generated by the parameter line method is shown in Fig. 8. The "3D dynamic" simulation result of the blade finishing is shown in Fig. 9.



Figure 8. Blade finishing tool path of impeller

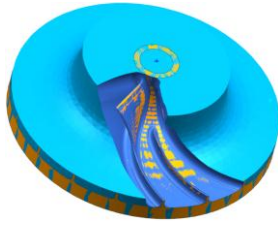


Figure 9. "3D dynamic" simulation results of blade finishing

4) Tool path planning for impeller blade finishing:

Blade root fillet machining is an important process in the whole micro integral impeller machining, which plays a transitional role in the connection between the blade and the hub, increases the overall rigidity of the blade, and has an important impact on the machining effect of the whole workpiece. In the first two processes of fillet path planning, the diameter of the tool used is larger than the fillet radius, which makes it impossible to process the fillet radius of the specified size after the blade and hub are finished. It is necessary to finish the fillet with the tool size equal to or less than the fillet radius.

The relationship between the radius of the finishing tool and the radius of the fillet determines whether the cleaning of the fillet is necessary after the finishing of the blade and the hub. Because the radius of the fillet is 0.5mm, the tool cannot cut to the fillet after the finishing of the impeller hub. Therefore, it is necessary to establish the fillet root cleaning process to complete the processing of the transition surface of the blade and hub, increase the overall rigidity of the blade, and the planned fillet tool path is shown in Figure 10. The "3D dynamic" simulation results of fillet finishing are shown in Figure 11.

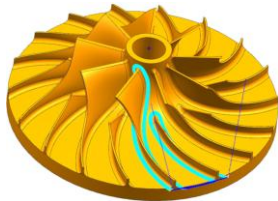


Figure 10. Blade root fillet finishing tool path

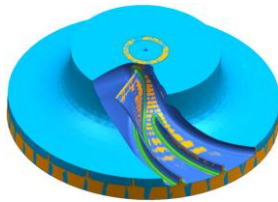


Figure 11. "3D dynamic" simulation results of blade root fillet finishing

C. Post-processing based on Siemens NX

The trace file generated by Siemens NX programming can not be directly used in the actual machining of machine tools, so it is necessary to generate the NC code program that can be recognized by the CNC system of machine tools by post-processing the trace file. NX post-processing is to

format and convert the tool path file generated by NX machining into a program that can be read and executed by a specific type of machine tool and controller. As the machine tool system used this time is FANUC system, it is necessary to process the track code generated by Siemens NX into the NC program under FANUC system, and the final NC program is shown in Fig.12.

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N0010 %
N0020 G40 G17 G90 G71 G54
N0030 G91 G28 Z0.0
N0040 T05 M06
N0050 G00 A-68.077 C289.364
N0060 G43.4
N0070 G90 X18.891 Y6.568
N0080 S2200 M03
N0090 G43 Z215.918 M05
N0100 G91 X9.817 Y3.898 Z211.706 F1000. M08
N0110 X8.142 Y2.79 Z211.332 F500.
N0120 X8.644 Y2.967 Z218.01
N0130 X8.323 Y3.879 Z218.011 F1000.
N0140 X8.297 Y3.948 Z218.015
N0150 X8.32 Y3.965 Z209.946
N0160 X8.331 Y3.993 Z209.899
N0170 X8.357 Y3.968 Z209.858

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Figure 12. Micro integral impeller numerical control track code

IV. NUMERICAL CONTROL SIMULATION BASED ON VERICUT

Due to the different motion characteristics and component construction of each machine tool, the post-processed NC program cannot be directly used on a specific machine tool. It is necessary to build a virtual machining environment through simulation software, and to ensure the machine tool in the actual machining process. The type of motion and the same construction ensure the correctness and feasibility of the tool path program and safely complete the actual machining process.

A. Establish VERICUT simulation environment

Because the CNC machine tool is i5M8 five-axis CNC machine tool, it is necessary to build the movement model of the machine tool. The i5M8 machine tool is A cradle type moving structure, which is mainly composed of three moving axes X, Y, Z and two rotating axes A and C. All parts on the machine need to be 1:1 in proportion to the actual 5-axis machine. A, C is the cradle type two axis machine tool, called machine file, select file system control fanuc32im.ctl, add tool library tls files, blank and fixture stl model file is added to the component tree, and set the machine tool interference, collision, distance, etc., are virtual machine components, and add the post-processed NC program to the simulation environment.

B. Numerical control machining program simulation verification

After completing the establishment of machine tool motion model, the addition of NC system, the establishment of tool library and the addition of NC program, the simulation machining of tool path is carried out to verify the correctness of the trajectory and the safety of the actual machining process, so as to ensure that there is no collision and interference in the actual machining.

The simulation processing of the micro impeller adopts the same parameters as the i5m8 five axis machining center. Before the simulation processing, the verification target can

be set to facilitate the viewing and correction of the results. Use red to represent the over cut part and blue to represent the residual part. After the simulation is completed, you can use VERICUT's analysis auto comparison function, i.e. "auto comparison" button to visually see the problem part through the color change of the part and correct the processing procedure.

After the simulation processing is completed, it can be seen from the simulation results of the micro-integrated impeller as shown in Fig.13. After the processing is completed, there is no obvious red and blue cutting parts, indicating that no overcutting and residual phenomena occur after the processing is completed; During the whole simulation process, there is no collision alarm phenomenon, indicating that the tool path program is safe and reliable, and can be used for actual processing and production.

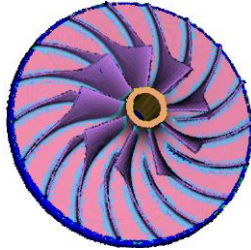


Figure 13. Simulation results of micro integral Impeller

V. VERIFICATION OF ACTUAL MACHINING TEST

In order to verify the rationality and correctness of the trajectory code in the five-axis NC machining trajectory planning programming for the micro integral impeller, it is necessary to apply this method to the actual machining to make the trajectory planning scheme more persuasive. Therefore, with the help of i5M8 five-axis NC machining center, the micro integral impeller trajectory is actually machined.

A. Test equipment and conditions

The main equipment and tools to be used in this processing experiment are shown in Fig.14:

- Micro-integrated impeller machining: i5M8 five-axis linkage CNC machining center, the planned trajectory code is imported into the machine tool, and two pieces (pre-optimized and optimized) tiny integral impeller are trial-produced;
- Tool: tapered 2-blade ball end mill with cemented carbide (YG uncoated)
- Machining the workpiece: the material is 7075 aluminum alloy, and the bar is $\Phi 35 \times 13$ (mm);
- Processing method: five-axis linkage milling (cutting fluid);

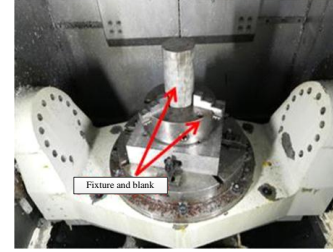


Figure 14. Micro integral impeller processing equipment

B. Milling experiment

Firstly, the previously planned and post-processed trajectory codes (before and after optimization) are sequentially introduced into the machining center machine. After the micro-impeller blank is installed, aligned, and the tool is calibrated, the machine can be started to perform the micro-impeller. machining. In the five-axis simultaneous milling process of the tiny integral impeller, the wet cutting method with cutting fluid is adopted, which has certain protection effect on the wear of the cutter, thus ensuring a certain cutting efficiency; and taking into account the stroke problem of the machine tool, avoiding the stroke shortage can not be achieved. The accurate cutting of the workpiece is carried out by the method of raising the bar material and cutting it after the impeller is formed, and the final product of the impeller after rough processing and the small integral impeller after finishing processing is shown in Fig. 15.



Figure 15. Micro integral impeller after machining

VI. CONCLUSION

According to the structure shape and basic size of the micro integral impeller to be studied, the tool path of micro impeller machining is planned, and the feasibility of the path is verified by machining simulation software. Finally, the verification test is carried out. Through the completed work, the following conclusions are drawn:

- Based on the structural characteristics of the tiny integral impeller, the impeller processing module of Siemens NX numerical control programming software is used to numerically control the micro-integrated impeller. The numerical control machining of the tiny integral impeller is divided into the stages of flow path roughing, runner finishing, blade finishing and blade root rounding. The path of the impeller machining is preliminarily determined.

- The tool path generated is simulated by combining 2D dynamic simulation and 3D dynamic simulation in Siemens NX, and the corresponding NC program is generated by special post finger processing.
- The VERICUT simulation software is used to simulate the machining of the micro integral impeller to verify the feasibility of the path, thus eliminating the trial cutting stage of the actual machining, initially ensuring the correctness of the path planning of the micro integral impeller tool path, avoiding the occurrence of interference in the actual machining process, and improving the machining efficiency.
- The correctness of tool path and NC machining program is verified by five axis milling of micro integral impeller. In the actual machining process, the machine tool runs smoothly, there is no imagination of interference and collision, and there is no over cutting and under cutting of impeller, which has certain guiding significance for the future NC programming machining of complex surface parts such as micro integral impeller.

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