Study on Machining Strategy and Vericut Simulation of Centrifugal Impeller Based on Hyper Mill

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Abstract: Centrifugal impellers are a centre segment of aircraft engines. The machining nature of the impeller straightforwardly affects its service life and mechanical properties. However, the complexity of the impeller blade surface and the requirement for a high degree of accuracy in the finished product means that the process of manufacture is complicated by the need to afford unimpeded access for the cutting tool. This paper describes research into CNC programming and the use of simulations to control the cutting tools, reducing machining errors due to such factors as distortion, collisions and interference. This is especially important where delicate and intricate machining is required as in the example of centrifugal impellers described in this thesis. Therefore, multi-axis NC machining theory, tool envelope surface theory, error compensation principles, numerical simulation technology, post-processing development for five-axis CNC machine tool of dual turntable, simulation and optimization for NC machining of Centrifugal impeller, planning for machining process of impeller and other technical methods were comprehensively studied.

Keywords: Centrifugal Impeller, Post Procession, Simulation, Five-axis side milling, machining error, Hyper Mill

1 Introduction

Centrifugal impellers are a kind of complex part with highly curved surfaces and very important components in petrochemical engineering, ships, aircraft industry, and so on.
Meanwhile, it is also the key component of the aircraft engine and the compressor impeller\(^1\). The design, programming and simulation of the cutting process, and finally, manufacturing of a centrifugal compressor impeller are three separate but important processes. A central feature of these impellers are the complex curved surfaces of the blades. Traditionally, there are two possible approaches to manufacturing such turbo machinery components, investment casting and machining. In order to obtain a dimensional accuracy within a desired tolerance for the blade surfaces, machining is the usually the preferred option. However, the complex geometries of impellers make this a challenging problem.

In the proposal of blade surfaces of Turbomachinery parts, two kinds of surfaces including sculptures and ruled surfaces may be measured \(^2\). A ruled surface is enclosed by straight lines, called rulings or rectilinear generators, which form a intimate with one parameter. Owing to this specific, ruled surfaces are most often applied to simplify the blade surface design when related with free form, sculptured surfaces. The impeller mold in the manufacturing process requires more complex technology, manufacturing difficulties; in addition, after the completion of the mold on the impeller production time mold will be very difficult, it is likely to damage the impeller blades, resulting in a larger scrap rate\(^3\). Five-axis machine tool has become the main processing and manufacturing equipment of complex parts manufacturers, so that the five-axis CNC machining of the whole impeller has gradually become a commonly used processing and manufacturing method.

The generation of tool path is the key to realize multi axis NC machining, which includes tool path planning and tool location. The calculation, cutter position interference check, correction, and post-processing of the cutter position\(^4\). The establishment of reasonable tool path planning greatly improves the production efficiency and surface quality after machining. Therefore, this is very important to arrange the order and plan the processing path. In order to get higher accuracy, it is necessary to optimize the tool path. After the tool path is planned, the post-processing is need to import the code that can be recognized by the machine tool. Tool is based on the machine tool the actual machining of 5-axis CNC machine tools\(^5\).

Through the growth of computer technology and development of machine tool manufacturing technology, simulation software is used to simulate NC machining, which plays an increasingly important role in numerical control technology\(^6\). Numerical Control simulation Technology can verify the correctness of the numerical control program through the virtual machining of the parts. Identify and solve some problems that may be encountered in the actual
processing in time, to shorten the design and development cycle of the product and reduce the production cost, so that the product processing quality and efficiency can be greatly improved, and can be used as a new development tool[7].

2 Machining Program for Centrifugal Impeller on Hyper Mill

The Centrifugal impeller is the most typical portion of 5-axis machine tool NC machining. In command to achieve the processing procedure of the Centrifugal impeller, it is basic to process it before that, according to its geometric parameters and processing characteristics, the corresponding NC machining process planning was formulated, and the tool path was generated. Milling is carried out from roughing to finishing. The task of rough machining is to cut off blades. A large number of materials show the shape of the impeller preliminarily. In addition, according to the actual needs of the semi-finishing process settings, Re-cutting the surface allowance left by roughing, removing the surplus material at the corner, and forming a uniform processing surface preparation for further finishing process. After the impeller is formed by semi-finishing operation, the impeller needs to be stamped out. The task of finishing is to gain the required accuracy and surface quality of parts.

2.1 Selection of Tool for NC Machining

In NC programming, reasonable tool selection is an important part of NC machining process planning for Centrifugal impeller. It not only affects processing efficiency also has a direct impact on surface quality. When choosing cutting tools, the first thing to consider is the type of machine tools and the choice of cutting tools. To be consistent with the machine tool that completes the process, secondly, the tool selected should be easy to install and adjust. In addition, the tool material must be consider. Tools are made of various materials, including alloy tool steel and carbon tool steel, which have low hardness and poor cutting performance. Cubic boron nitride, ceramic and diamond tools are expensive, the tools used in this research ball milling tools of aluminum alloy.

2.2 Rough Machining of Impeller Hub

The machining difficulty of Centrifugal impeller is mainly manifested in the complex blade profile, the limited space of impeller runner and the large depth of Hub. It is very easy to produce interference and collision between tool holder and blade in the process of machining. Roughing occurs pocket-by-pocket between the main blades. Different roughing strategies optimize path distribution, tool inclination and the tool length for the machining task. The same applies to the
adjustment of the feed rates an area at a time and to several other detail features. The selected milling strategy determines the tool inclination and the axial path distribution. The cut division are calculate as an offset to the shroud starting from the first path. The paths are trimmed against the hub surface and extended on this surface to the next-highest path. In Hyper Mill, the driving mode of variable-axis profile milling is used to define the driving point when creating tool path. In variable-axis milling, a variety of driving methods are provided, such as curve, point, boundary and surface area.

The tool used for rough machining is ball mill tool with specification of R2B3D8. The length of the tool is 75mm with the diameter of 8mm. the maximum step over is 1.3 and step down is 1. The allowance of Hub and blade is 0.5. There are total 14 blades including 7 small and 7 big blade. The feed rate is 1500 and spindle speed was 8000rpm. The Program is shown in figure 2.1

![Figure 2.2 Rough machining of Runner/Hub](image)

2.3 Finishing of Runner /Hub and Blade

For blade finishing, similar to Hub roughing, the selected machining operation is variable axis profile milling, and the selected drive method is surface. The same tool has been used
for the finishing of blade with different milling strategy. The milling reference choose main blade with the entry position on leading side and parallel to hub will keep the hub allowance 0.4 and blade allowance 0. The program shown in figure 2.2.

Fine machining of impeller hub surface is the last and important step of impeller processing, which removes impeller hub surface residual material ensures the machining accuracy of impeller hub surface. The method of tool path generation is same to that of rough machining of hub. The milling strategy is complete the edge rolling is leading edge as well the entry position is trailing side and the tool path is flow zigzag. The scallop height of 0.1 and the edge tolerance will be 0.01. In the allowance section of hub allowance 0 and the blade allowance 0.25. The machining trajectory is shown in fig 2.3 the machining trajectory of the whole impeller.

![Figure 2.2 Blade Finishing](image1)
![Figure 2.3 Hub Finishing](image2)

2.4 Creation of Post-Processing

Post-processing is an important part of NC machining. Because the controllers of different NC machine tools are different, the source files of tool path generated by post processor software cannot be directly used by the control system. It is necessary to use post-processing tools to transform tool path source files into NC codes that can be recognized by specific machine tools. This paper uses hyper mill post-processing development tools to create special post-processing files. Users can create event-processing files and event definition files related to the control system.
of any machine tool according to their needs, and complete the task of post-processing construction of machine tools.

Using the post-processing constructor of Hyper Mill software to create the post-processing of milling. For the DMU 65mono BLOCK five-axis milling compound center machine tool used in this study, we will establish a post-processing integrated with the five-axis machining center. Establish a new five-axis milling machine tool post-processing, named HTM_millturn_5axis, for Z-axis milling enter the link post-processing options under the program and tool path tab, check the "link other post-processing to this post-processing" option, and then link the lathe post-processing and milling machine post-processing established before. Open the program and tool path tabs, enter the text arrangement option, and then round off the functional words, and finally save the post-processing.

3 Machining Simulation and Manufacturing of Centrifugal Impeller
Before NC machining of Centrifugal impeller, in order to ensure the smooth process of machining, it is necessary to simulate NC machining on computer by means of three-dimensional graphics technology. Which can evaluate the correctness of NC program more accurately, avoid repeated trial cutting on machine tool during actual processing, reduce material consumption and cost, and
increase the addition of NC program work efficiently. The standard files in STL format built before are imported into VERICUT, loaded and assembled; the geometric and kinematic models of the machine tools used are established. VERICUT software is a simulation software developed by CGTECH Company in the United States. It is used in the simulation demonstration process of NC machine tools. The software can be used in the simulation of machine tools and cutting simulation software. It can be used to simulate the processing operation process of multi-axis milling, cobalt, turning and other machine tools. It can be model by human-computer interaction. To verify and display NC programs, it is a leading example of NC program verification software in the world. The virtual machine tool is a model, which is reconstructed according to the logic and motion relationship between the original parts after simplifying the original large-size parts. The model can reproduce the real machine tool processing simulate the process of processing. According to the structure of DMU 65 Mono Block five-axis NC machine tool for Turning-Milling compound machining Centre, the main mechanical structures can be refined. The tree diagram and virtual machine diagram showing in figure 3.1 and 3.2 respectively.

Fig. 3.1 Tree diagram

Fig. 3.2 Virtual machine with fixture
3.1 Establishment of Tool Library for NC Machine Tools

The establishment of tool library is indispensable for NC machining. The corresponding tool library files can be established by VERICUT simulation software before simulation processing. The tool information needed to define the tool library includes the tool. Information on tool type, tool diameter, length, and tool grip point and tool tip are provided in VERICUT Existing in * tls file format. The tool number in the tool library should be matched with the tool number in the program. We build the tool library of this subject by creating turning tools and milling tools in the blank Tool Manager shown in Figure 3.3. The simulation tool library constructed by this subject is shown in Fig. 3.3. The driving points, cutting edges, shanks, rods and clamping points of turning and milling cutters are shown. The cutting edges, shanks and tool holders of the cutters should be kept as close as possible to the tool parameters used in programming.

![Figure 3.3 creating a simulation Tool Library](image)

3.2 Machine Simulation and Manufacturing Results

Import the program into VERICUT, select the "reset model" in the lower right corner to initialize the model, and then select the last button "simulation to the end", so that the simulation can be carried out. Looking at the VERICUT log, we can see whether there are errors (collision, over-...
cut or under-cut, etc.) and where the errors occur during the simulation process\cite{8}. When errors occur, the indicator light below the simulation interface flashes prompts. We can see the rough machining of impeller in figure 3.4

After roughening, the basic outline of impeller parts can be seen. Because the remaining amount of roughing is 0.2mm, semi-finishing is needed, but directly finishing is carried out. Choosing the leading side feed tool, the lateral feed is optimized by two-way streamline. The maximum step distance of feed is 0.3, the channel allowance is 0.5, and the blade allowance is 0.25. The leading edge of the extended blade is 2, the trailing edge of the blade is 1, and the five-axis linkage machining is adopted. The strategy of avoiding collision is around the Z-axis as shown in figure 3.5 below

![Fig. 3.4 Simulation of Rough machining](image1)

![Fig. 3.5 Actual rough Machining of Impeller](image2)

After finishing of rough machining impeller is next step is to do finishing of hub and remaining the allowance 0. Simulation and machining of finishing hub is showing in figure 3.6 and 3.7 respectively.
After finishing the runner, the next step is to finish the blade. The blade surface of impeller belongs to complex surface. Traditional three-axis machine tools cannot be machined, and can only be realized on multi-axis machine tools. As the core component of the turbine, the surface quality of the impeller directly affects the output effect of the engine. Therefore, in the NC machining of impeller, it is necessary to work out a reasonable processing technology, select a better combination of cutting parameters, and select a suitable NC machine tool to produce a better impeller surface quality. The blade structure of impeller belongs to thin-walled parts, and the distance between the blades is narrow. The cutting space of the tool is very limited, and the cutting rate of material is very high. Here, we choose to process the long blade preferentially, choose the exit side of the feed position, choose the flow line horizontally, the maximum step distance of the feed rate is 0.5, the hub margin is 0.05, the blade margin is 0, five-axis linkage processing, and the strategy of avoiding concession is to choose around Z axis, special function. The menu selection is close to the blade to avoid over-cutting and interference. The simulation and manufacturing results are showing in the picture below.
As we can see in the above picture, simulation results indicate that there is res zone. Therefore, its means that our tool path planning and program is right as there is no tool collision and no interference with fixture and workbench. On the other hand, the machining of impeller is done successfully without any overcut or damage of parts.

4 Conclusion

The whole impeller is designed by UG/CAD, and Programmed by Hyper mill/CAM and Hyper mill Post builder program used in DMU 65. The interference processing, tool path planning and tool path error in five axis side milling of centrifugal impeller are reviewed based on the analysis and control, the prediction of machining deformation and the research status of error compensation, aiming at the problems of cutter interference and machining deformation error in the current five axis NC machining of centrifugal impeller. The special post processor for the development of double turntable five axis CNC machine tool is based on the software VERICUT Machine simulation, optimization path and other modules are used to simulate and optimize the numerical control machining of Centrifugal impeller, and finally to complete. The whole impeller is simulated and machined by VERICUT simulation software, and the correctness of tool machining path are verified availability of post-processing. In the process of simulation, the collision between tool and work piece occurs. In the program, it can be solved by adding the command of tool return to reference point. The constant volume removal rate used to optimize the machining path, which
improves the efficiency of adding work efficiency. The solid processing of impeller model is demonstrated. As well, this paper introduces the automatic programming technology of impeller and five-axis machining machine tool, formulates the processing technology of impeller, and designs a set of special fixtures for its machine tool processing. There is no interference or collision between the tool and the work piece in the simulation process. Finally, the generated tool path processed after the program, and the program imported into DMU65 five-axis machine tool. The work piece is not over-cut or under-cut and the surface quality of blade meets the requirement of result verification.

Reference

Conflicts of Interest
There are no conflicts to declare.

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