Multi-axis NC machining of integral impeller parts based on NX

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Abstract. The Integral impeller is widely used in all kinds of turbine machinery and aeroengine. With the improvement of engine performance, the shape of the impeller becomes more and more complex. It has the characteristics of small blade spacing, large distortion and thin blade, etc. The Integral impeller is more difficult to process. This paper analyzes the NC machining technology of the Integral impeller and discusses the parameter setting of the multi-axis NC machining.

1. Impeller and machining methods
Impeller is the core component of turbine machinery, widely used in aerospace, nuclear power, automobile, metallurgy and other fields. [1] The integral impeller designs the blade and hub into a whole structure, which reduces the number of parts, the total weight, the loss of air flow, the possible crack initiation and propagation at the tenon groove, and improves the efficiency and reliability of the engine. The machining accuracy of impeller directly affects the performance and working reliability of the equipment.

Nowadays, for the high engine performance, the shape of the integral impeller is more and more complex, and becomes a kind of typically hard-to-cutting parts. In order to ensure the impeller has good aerodynamic performance in the high-speed running of turbine machinery, the impeller adopts thin-walled multi-blade, large torsional angle of blade, and the blade root adopts the changing rounded angle. These factors all put forward the strict requests to the whole impeller processing.

1.1. Structure of integral impeller
The integral impeller is mainly composed of hub, main blades and shunt blade. The blade is uniformly distributed on the hub surface, and there is a shunt blade between the two adjacent main blades, and its space forms a circulation channel on the hub surface. The connection between each blade and the hub has an inverted transition surface to ensure smooth splicing between the blade and the hub surface. [2]

1.2. Impeller machining method
There are two traditional methods for producing impellers: one is polishing after casting, which is difficult to ensure the accuracy and strength of the blade, and the other is forging. It is only suitable for machining impeller with simple blade shape, and it needs very complex forging die.

Multi-axis NC machining is widely used in integral impeller parts because of its advantages of quick reaction, high reliability, good machining flexibility and short production preparation period. Multi-axis NC machining technology of integral impeller mainly involves: tool selection and optimization technology, non-interference tool bit trajectory planning technology, high efficiency and precision...
machining technology, cutting force and cutting temperature prediction technology, surface integrity and anti-fatigue manufacturing technology, etc.

Multi-axis NC machining difficulties of integral impeller are as follows: the number of impeller blades is more and the middle distance is narrow, so it is necessary to select small diameter cutting tools, which are easy to break when the force is large in the machining process, so it is a key problem to control the cutting depth and width of the cutting tools. [3] The blade design adopts thin-walled and double-supported beam structure, the blade length is relatively long and the rigidity is poor, so vibration control and residual stress deformation control are important in machining process. The blade surface of the whole impeller adopts free surface, the flow channel is narrow, the distortion is quiet usual, there are many negative angle structures, the openness is poor, the numerical control programming is difficult, and it is easy to collide in the machining process. At the same time, with the change of the cutter shaft, the effective cutting diameter of the ball cutter changes, which will result in the fluctuation of surface quality. Reasonable tool path planning will help to improve machining efficiency, prolong tool service life and improve workpiece surface quality. Interference, collision, vector mutation of cutter shaft and discontinuity of easy to occur in Multi-axis NC machining programming of integral impeller. All these require in-depth research on the tool path planning method of impeller Multi-axis NC machining, and make the tool axis vector change more smoothly without interference with the workpiece, so as to obtain a better-quality tool track file.

2. About UGNX software
NX is a CAD/CAM/CAE integrated software developed by SIEMENS company, which includes modules such as entity modeling, virtual assembly, engineering drawing, numerical control programming, motion simulation, and NX PostBuilder. [4] Using the UG NC machining module, the visual tool path can be quickly generated according to the established machining process, and the NC machining G code can be generated by calculating the tool path through the post-processing module. The NC machining G code is transmitted to the five-axis NC machine tool after debugging. UGNX software is used to program the integral impeller.

3. Multi-axis NC programming of integral impeller
The integral impeller studied in this paper is shown in fig 1, It is a semi-open structure consisting of one hub, six main blades and six shunt blades. The overall impeller height is 79.36mm, the maximum diameter is 176mm, the blade height is 38.94mm, the minimum thickness is 1.13 mm, the average blade thickness is 1.79mm.

![Fig 1 Structure of the impeller](image)

The whole part is made of aluminum alloy material, which is light in weight and high in strength, has the specific strength of close to high alloy steel and exceeds the specific stiffness of steel, has good casting performance and plastic processing performance, and has good corrosion resistance. Due to the
high requirement of performance and quality of parts, machining will be divided into three stages: rough machining, semi-finishing and finishing.

3.1. Rough programming of impeller

The blank is clamped with a three-claw chuck, and the runner surface, blade and shaft hole of the impeller are rough-milled, which is used for removing a large amount of cutting allowance, ready for the next finishing. In the process of impeller rough machining, the machining efficiency is considered emphatically. [5] Because a large number of materials need to be removed in a short time, the requirement of surface quality is not high. Therefore, it is necessary to plan the tool track reasonably and improve the rough machining efficiency. The rough machining stage can be processed by 3+2 directional machining or special impeller machining module. 3+2 directional machining is a traditional three-axis machining with A, C axis positioning, which moves faster. However, due to the large number of blades and shunt blades impeller parts, the processing area is narrow, it is necessary to carry out many A, C axis orientation, and the programming operation is more complicated. Impeller machining module is a feature-based programming method. By specifying each component of the impeller, the software identifies the geometric characteristics and dimensions of the impeller, and inputs the specific parameters of impeller cutting according to experience. Different from basic module programming, the special module can automatically adjust the angle of cutter shaft, the programming efficiency is higher and easy to process.

First set up machining coordinate system MCS and select machining tool in impeller machining module. "MCS_MILL" coordinate system is a reference point for tool path and a point for machine tool position determination. The coordinate system should consider the possibility of workpiece alignment and the convenience of measurement during machining, so as to avoid the deviation of dimension chain and measurement error caused by positioning. The machining coordinate system takes the impeller top surface as the X axis and the Y axis plane, and the Z axis is the central axis of the impeller hub. In order to avoid blade better in processing, the ball knife with taper diameter of 6mm is selected. The impeller machining geometry is then arranged to specify the impeller hub, cladding, blade, blade root corners and shunt blade. Set cutting speed at 8000 r/min, feeding speed at 500 mm/min, each cutting depth is set to 2.5 mm, set workpiece machine allowance at 0.5 mm, cutting mode selection reciprocating upward, the cutting direction is set to down milling. Cutting step is set to 2 mm, blade edge is set to extend 2 mm along blade direction. Cutting depth mode set to offset from hub, Other parameter settings default. The resulting toolpath is shown in figure 2. In this way, the rough processing of a blade and a shunt blade is completed. By using the transformation command to copy the rotary shaft around the impeller, the other 5 blades and shunt blades can be generated.

3.2. Semi-finishing programming of impeller

The purpose of rough machining is to quickly remove the most material so that the shape of the workpiece after rough machining is roughly completed, but before finishing, due to the setting of the size of the rough machining tool and the limitation of the machining depth, etc. Rough cutting tools are
not machined in some areas. A large amount of material may be left in some areas of the workpiece, but when finishing directly, due to the uneven material retention, the cutting quantity increases, the cutting resistance increases, and the tool wear is accelerated. And the quality of processing can not be guaranteed, or seriously, may result in under-cutting or overcutting. The semi-finishing process is programmed by the special processing module of impeller, and the main blade, shunt blade, hub and impeller fillet are processed respectively. Choose a 4 mm diameter ball knife for processing. Set machining allowance to 0.2 mm, spindle speed at 10000 r/min, feed rate at 1000 mm/min, Cutting mode of main blade and shunt blade are set to reciprocating, cutting direction is mixed, cutting direction is along blade, constant distance of each cutter is 0.15 mm. The cutting mode of hub machining is reciprocating, the cutting direction is mixed, and the cutting direction is along the blade The cutting mode of blade root corners are set to one-way, the cutting direction is set to down milling, constant distance of each cutter is 0.1 mm. The entire semi-finishing tool path is shown in figure 3.

3.3. Finishing programming of impeller
The finishing process is to ensure the specifications of the parts meet the requirements specified in the drawings, Final inspection and treatment of impeller finish milling runner surface, blade and shaft hole to meet the final design requirements. The finishing settings are similar to semi-finishing, which is explained above, so here is omitted.

3.4. Machining simulation of impeller
Application NX software to simulate tool path. Compare the overcut and undercut between the finished parts and the design to determine whether the program needs to be modified and optimized. After virtual machining of the impeller, the tolerance is set to 0.1 mm to detect whether the workpiece is undercut and overcut. After comparison, there is no overcut and undercut, As shown in figure 4.

4. Conclusion
By using UG NX software, this paper analyzed the structure and machining difficulties of the complex curved impeller model, planned the machining process and compiled the rough machining/finishing machining tool path, selected the machining tool reasonably, selected the suitable machining method according to the characteristics of the runner and blade, and compiled the machining tool path of the
Integral impeller. The Integral impeller NC machining scheme was operable and the machining effect was quite satisfactory.

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