Joint simulation machining study of inducer based on MAX-PAC and VERICUT

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Abstract. The inducer is a part with a complex curved structure and is widely used in the energy, aerospace and petrochemical industries. To improve the efficiency of the inducer machining, a 5-axis machining path was prepared using the CNC machining programming software NREC MAX-PAC. The NC code was exported to VERICUT CNC simulation software through a customized post-processing program by IMSpost to verify the validity of the CNC program. Compared with the original machining time, the actual machining time is now shortened by 43.18% after optimization, which realizes the efficient milling of complex inducer structure.

1. Introduction

Inducer is an important component of liquid rocket engine turbine pump, the traditional inducer is first made into a blank by casting process, and then trimmed into a finished product [1]. As the surface structure of the inducer wheel becomes more and more complex, it is difficult to make the casting mold, which leads to low processing efficiency, difficult processing and difficult to guarantee the surface quality[2]. In order to improve the processing efficiency and surface quality of the inducer, it is imperative to study the efficient milling process of the inducer.

At present, most parts of the CNC programming are usually done using general CAM software such as UG, PowerMill, HyperMill, etc. [3,4]. The inducer and similar structure of impeller and turbine parts usually have the characteristics of large changes in curvature of the surface and complex structure, which makes it difficult to program the machining of such parts [5]. It requires High demand for CNC programmer ability. This study will use NREC MAX-PAC software for CNC programming of inducer machining, which is an impeller structure development software integrating impeller design, analysis and manufacturing. It can generate machining tool paths according to the impeller structure, which greatly improves programming efficiency and reduces the difficulty of impeller structure programming.

2. Analysis of inducer machining process

The geometric model of the inducer to be machined is shown in Figure 1. The main features of this inducer are the hub surface (gray features), large blades (red features), small blades (blue features). the material of this inducer is aluminum alloy ZL114.
According to the inducer structure characteristics, there are several machining difficulties: (1) large blade twisting angle is large and more than $180^\circ$, CNC programming is difficult; (2) the number of blades is large. The space between the blades is narrow, easy to interfere when processing, need to use a small diameter tool. And the blade width is large, requiring a longer tool, resulting in poor rigidity of the tool; (3) the material of the inducer is aluminum alloy, aluminum alloy is easy to stick when processing, affecting the processing quality; (4) the thinnest part of the blade thickness is only 2mm, aluminum alloy thin wall parts rigidity is poor, finishing machining surface quality is difficult to ensure.

Plunge milling is a process that can significantly improve efficiency, especially in the roughing stage. Unlike plane milling, its unique machining method can reduce the deformation of the workpiece during machining and reduce the radial cutting forces acting on the milling machine. And for the case of large tool overhang length, plug milling is very favorable, so the inducer processing process is as follows.(1) Hub surface plug milling: The distance between the part blade and hub surface reaches 98mm at the maximum, in order to prevent the tool overhang too long, the plug milling rough machining of the part in two steps, the first plug milling depth of 55%, the second plug milling after 46%, to ensure the rigidity in processing and extend the tool life; (2) Large blade semi-finish machining: Due to the large twisting angle of the large blade, the A and B sides of the large blade need to be semi-finished separately. Because the residual height left by the insert milling is not uniform, need to use a larger diameter tool to improve processing efficiency, the tool used in this study is D25R4 round nose milling cutter, to ensure that the balance of the finishing machining is uniform; (3) Small blade semi-finish machining: Small blade torsion angle is small, can be simultaneously on the small blade of the A, B surface for semi-finishing machining, the same use of D25R4 round nose milling cutter; (4) Large blade finishing machining: Similarly, the finishing also need to separate the A, B surface of the large blade, in order to ensure the processing quality, using the way of smooth milling, and use the smaller diameter tool SR6 ball milling cutter; (5) Small blade finishing: Finishing of the small blade A, B surface, the same use of SR6 ball milling cutter, smooth milling cutting method; (6) Hub surface finishing: Using SR6 ball-head milling cutter with reciprocating cutting method to improve machining efficiency. The specific process parameters are shown in Table 1.

| operation number | process name                        | cutting tools           | spindle speed(rpm) | feed rate(mm/min) | machining allowance(mm) |
|------------------|-------------------------------------|-------------------------|-------------------|-------------------|-------------------------|
| 1                | rough plunge milling of wheel face   | D20R2 plunge cutter     | 1500              | 180               | 1.5                     |
| 2                | finish plunge milling of wheel face | D20R2 plunge cutter     | 1500              | 240               | 0.5                     |
| 3                | semi-finish machining of large blades | D25R4 round nose milling cutter | 1700              | 180               | 0.2                     |
3. Simulation of machining paths in MAX-PAC
To carry out CNC programming of machining toolpath, first of all, the model needs to be imported into MAX-PAC software and extract the data of each feature on the inducer structure, including blade A surface, blade B surface, hub surface, blade leading and trailing edge and blade fillet, etc. The software will build a model according to the extracted features and use this model as the basis for toolpath programming.

Subsequently, the machining of each part of the inducer can be CNC programmed, and the CNC programming process of the finishing of the small blade is taken as an example to illustrate. (1) Select the machining strategy: Rotary machining of small blade A, B surface, milling type select smooth milling, and check the processing of small blade top edge and bottom edge (see fig.2-a). (2) Set the number of tool path and machining range: Setting the residual ridge height 0.2mm to determine the depth of cut direction step, machining range for the entire blade, that is, the depth direction and length direction are set to 0 ~ 1 (see fig.2-b). (3) Set the machining allowance: The machining allowance of the small blade is set to 0, while the machining allowance of the hub surface and adjacent blade is set to 0.3mm to prevent overcutting of the hub surface when machining the blade (see fig.2-c). (4) Set the tool axis direction: Using the point milling method and select five-axis cutting, the software will automatically calculate the tool axis angle according to the surface shape (see fig.2-d). After completing the above settings, the point file of the machining toolpath for small blade finishing can be generated (see fig.3).

| No. | Operation Description                        | Cutter Type | Feedrate | Depth  |
|-----|-----------------------------------------------|-------------|----------|--------|
| 4   | Semi-finish machining of small blades         | D25R4 round nose milling cutter | 1700     | 180    | 0.2    |
| 5   | finishing of large blades                     | SR6 ball end milling cutter     | 3500     | 180    | 0      |
| 6   | finishing of small blades                     | SR6 ball end milling cutter     | 3500     | 180    | 0      |
| 7   | finishing of wheel face                       | SR6 ball end milling cutter     | 3500     | 640    | 0      |
After generating the path, it needs to be post-processed to generate G-code before it can be used on the machine. Since NREC MAX-PAC software's own post-processing function is weak and can only output the point and normal file (apt code) of the tool path, IMSpost is used to customize the post-processing file. The software has rich customization functions and can customize suitable post-processing programs according to various machine structures and CNC systems.

The CNC machine used in this machining experiment is a C100P 5-axis machining center with Siemens 840d control system. The machine information is properly set in IMSpost software and the toolpath file is post-processed to generate NC code using the tool tip point following function.

4. Results
In order to avoid dangerous situations such as interference and collision, or overcutting and undercutting during the machining of the part, the validity of the program must be verified by CNC simulation before the actual machining. The machine model is built in VERICUT software, and the fixtures and parts are imported into the software to ensure that the simulation environment and the actual machining environment are identical. Figure 4 shows the machining environment built in the software.
Fig. 4 Simulated machining environment built in VERICUT

The NC program of the third part was imported into VERICUT software and the machining results were simulated. It can be seen that there is no interference or collision in the machining process, and there is no overcutting or undercutting and other undesirable phenomena (see fig.5). Simulated machining programs can be imported into five-axis CNC machine for actual cutting. The machining time before is 1068 minutes, and after optimization is shortened to 607 minutes, the machining time is shortened by 43.18%.

Fig. 5 Machining results of the inducer

5. Conclusions
The structure and machining difficulties of such inducers are analyzed, and the machining process of inducer is developed. Taking the finishing of the small blade of the inducer wheel as an example, this
The paper elaborates how to complete the planning of the tool path in MAX-PAC. The NC code file of the inducer wheel was generated by the IMSpost post-processing program and imported into VERICUT software for simulation machining, and the machining results showed that there were no overcutting and other undesirable phenomena, and the machining quality was good. The machining time was reduced by 43.18%, which improved the machining efficiency of the complex structure of the inducer.

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