Study on multi-axis simulated NC machining for thin-walled impeller

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Abstract. Thin-walled impellers are widely used in aerospace and other high-end manufacturing industries. However, the machining of thin-walled impeller is a difficult problem. In this paper, the simulated NC machining for thin-wall impeller with a wall thickness of 1.8 mm is presented. Firstly, the Three-dimensional model of thin-wall impeller with 18 blades is created in SolidWorks. The multi-axis NC machining processing for impeller includes is divided into four stages: roughing and grooving, finishing blade, finishing hub and finishing fillet. All the tool paths for the above-mentioned processing stages are planned by blade expert module in MasterCAM. The five-axis simulated machining for thin-walled impeller is carried out to detect abnormal phenomena such as tool collision by machine simulation module in MasterCAM. The study can simulate the real processing scene for multi-axis NC machining thin-walled impeller and improve the design of NC processing efficiency.

1. Introduction

Because of its light weight and compact structure, thin-walled impellers are widely used in aerospace and other high-end manufacturing industries. Because the thin-walled impeller has high integrity and complex surface, it needs to be machined from a larger blank, and the material removal rate can even reach more than 90% [1]. Therefore, it has higher requirements for machining efficiency and accuracy [2]. Besides, round corner milling cutters (including ball-end milling cutters) with geometric contour advantages and easy trajectory planning are widely used in machining thin-walled impeller [3]. In recent years, scholars at home and abroad have done a lot of research on thin-walled workpieces such as thin-walled impellers. Zhang J. et al. [2] analyzed the dynamics of the thin-walled workpiece based on modal experiments to obtain the transfer function and modal parameters of the tool-workpiece system, and the forced vibration response was then predicted using a time-domain method. The simulations indicated that a proper nose radius can suppress the forced vibration response. Gong Q. et al. [4] used Abaqus software to construct finite element simulation models with different machining allowances for the problem of unstable and inefficient cutting process of high thin-walled aircraft structural parts. Gao Y. et al. [5] used the finite element method to analyze the processing deformation of thin-walled workpiece and to optimize the cutting tool Track. Zhang J. et al. [6] proposed the tool movement model and milling force calculation model for five-axis flank milling blade with tapered,
helical, ball-end mills, and then geometrical simulation and milling force prediction were carried out for the semi-finishing or finishing process of complex surface such as integral impeller. Xiao S.[7] applied the expert system in MasterCAM X6 software to complete high-speed five-axis rough machining optimized parameter setting, and no collision, no past five axial impeller rough machining path trajectory was gotten. At present, the research mainly focuses on the analysis of forced vibration and optimization of tool path in machining of thin-walled workpiece. The shape of thin-walled impeller blade is complex, and its thickness is thin, and the flow passage space between blade and blade is narrow. It is difficult in actual CNC machining. It is easy to encounter interference, over-cutting, under-cutting and other phenomena, resulting in production safety accidents. In this paper, the three-dimensional model of thin-walled impeller is built by SolidWorks, and the tool path planning and virtual CNC machining simulation for impeller are realized by MasterCAM, which effectively improves the machining efficiency and accuracy.

2. Three-dimensional modeling of thin-walled impeller

The three-dimensional model of the thin-walled impeller is built in SolidWorks. The height of thin-walled impeller is 110 mm, the diameter of the impeller's baseplate is 400 mm, the height of the impeller's baseplate is 8 mm, the number of blades is 18, and the thickness of blade is 1.8 mm.

![Figure 1. Three-dimension model of thin-walled impeller](image)

3. NC machining process of thin-walled impeller

The thin-walled impeller has 18 blades, which are thin in thickness and poor in stiffness, and are prone to deformation during processing. The impeller runner spacing is narrow and deep, so it must be processed by long-handle tool. Generally, the stiffness of long-handle tool is poor and easy to break. In addition, the blade surface is complex, and interference and collision are easy to occur in the machining.

In order to overcome the above problems, multi-axis NC machining is used to process the thin-walled impeller. As shown in Table 1, the multi-axis NC machining processing for impeller includes roughing and grooving, finishing blade, finishing hub and finishing fillet. All the tool paths for roughing, finishing blade, finishing hub and finishing fillet are planned by blade expert module in MasterCAM.
Table 1. List of multi-axis CNC machining technology for impeller

| Processing          | Roughing and grooving | Finishing blade | Finishing hub | Finishing fillet |
|---------------------|-----------------------|----------------|--------------|-----------------|
| Tool                | Taper ball-nose end mill | Ball-end milling cutter | Carbide ball-end milling cutter | Ball-end milling cutter |

Because the space between adjacent blades is narrow and the curvature of the blade surface changes dramatically, the blade is prone to cracks and deformation during the processing. Therefore, in order to effectively avoid the occurrence of over-cutting and interference problems when the tool works between adjacent blades and in the runner, it is necessary to reasonably control the swing range of the tool axis to obtain smooth and smooth surface grain. Firstly, it should be processed according to the order from the middle position to the outer edge of the impeller, and set reasonable roughing allowance. Then, the roughing of the impeller groove should be carried out by using conical ball-end milling cutter with larger diameter. The finishing hub is accomplished by using a ball-end milling cutter with smaller diameter, which not only makes the surface of the hub more uniform, but also ensures higher machining accuracy. The milling sequence is that the milling cutter expands from the middle position to the outer edge, and reserves reasonable allowance for finishing blade. Finally, the process of cleaning blade root is completed at one time to reduce the cracks between the blade and the hub, and to ensure that the blade shape is complete and accurate.

3.1 Roughing and grooving
The spindle speed is set to 5000 r/min. The feed rate is set to 600 mm/min. The rough cutting tool is selected as taper ball-nose end mill, the diameter of the cutter is set to 6 mm and the clamping length of the tool is 80 mm. The cutting strategy is selected as offset from hub, the cutting method is selected as zig-zag (start from leading edge) and the cutting ordering is selected as from center away. The tool paths for machining the runner between two blades are shown in Figure 2. The tool paths for roughing and grooving are shown in Figure 3. The cutting paths are blue. Both the plunge paths and the retraction path are yellow.

3.2 Finishing blade
The spindle speed is set to 6000 r/min. The feed rate is set to 800 mm/min. The rough cutting tool is selected as ball-end milling cutter, the diameter of the cutter is set to 4 mm. The cutting strategy is selected as offset from hub, and the cutting method is selected as zig-zag (start from leading edge). Besides, the cutting direction is selected as climb cutting. The tool paths for machining the runner between two blades are shown in Figure 4. The different color definitions of the tool paths are as described above.

Figure 2. Tool paths for machining the runner
Figure 3. Tool paths for roughing and grooving
3.3 Finishing hub
The spindle speed is set to 6000 r/min. The feed rate is set to 800 mm/min. The rough cutting tool is selected as Carbide ball-end milling cutter, the diameter of the cutter is set to 4 mm. The cutting method is selected as zig-zag (start from leading edge) and the cutting ordering is selected as left to right. The tool paths for finishing hub are shown in Figure 5. The different color definitions of the tool paths are as described above.

3.4 Finishing fillet
The spindle speed is set to 6500 r/min. The feed rate is set to 820 mm/min. The rough cutting tool is selected as ball-end milling cutter, the diameter of the cutter is set to 3 mm. The cutting contour is selected as full contour, and the cutting method is selected as zig-zag (start from leading edge). Besides, the cutting ordering is selected as from top to down and the cutting direction is selected as climb cutting. The tool paths for finishing fillet are shown in Figure 6. The different color definitions of the tool paths are as described above.
4. Simulated NC machining thin-walled impeller
Because of the complexity of multi-axis NC machining, if the generated tool paths were directly generated into the NC program and imported into multi-axis machining center, there would be serious consequences such as production accidents. Therefore, it is necessary to inspect the abnormal phenomena such as collision in NC machining program generated by tool path through simulated machining. The multi-axis simulated machining for thin-walled impeller is completed by using machine simulation module in MasterCAM. As shown in Figure 7, Five-axis simulated machining for thin-walled impeller is carried out in MasterCAM.

5. Conclusion
The study on multi-axis simulated NC machining for thin-walled impeller proposed in this paper can effectively simulate the real processing scene, detect abnormal phenomena such as tool collision as early as possible, and improve the design of NC processing efficiency on the basis of reducing the design time.

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References
[1] Wang T., He N., Li L. (2007) Vibration model in milling of thin-walled components. *Chinese Journal of Mechanical Engineering*, 43:22-25.
[2] Zhang J., Liu C. (2018) Forced vibration response during the milling of thin-walled work pieces. *Journal of Tsinghua University (Science and Technology)*, 58:1-5.
[3] Ko T., Kim H., Lee S. (2001) Selection of the machining inclination angle in high-speed ball end milling. *The International Journal of Advanced Manufacturing Technology*, 17:163-170.
[4] Gong Q., Jiang Z., Sun C., Liu C. (2018) Research on efficient and stable cutting technology of high thin-walled parts. *Manufacturing Technology & Machine Tool*, 10: 20-24.
[5] Gao Y., Ma J., Jia Z. (2016) Tool path planning and machining deformation compensation in high-speed milling for difficult-to-machine material thin-walled parts with curved surface. *The International Journal of Advanced Manufacturing Technology*, 84:1757-1767.
[6] Zhang J., Lai X., Yan S. (2018) A cutting force prediction for five-axis flank milling of an impeller blade surface. *Journal of Engineering for Thermal Energy and Power*, 33:23-27.
[7] Xiao S. (2018) Research on impeller high-speed roughing machining path optimization setting. *Machine tool & Hydraulics*, 46:49-53.