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Structural Design and CNC Machining of Integral Impeller for Automotive Turbocharger

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Abstract. Integral impeller is a key component of turbocharger. Although the research on structural design and machining of integral impeller has made some progress, The technical route of design and processing of integral impeller for vehicle turbocharger is cumbersome and slightly less efficient. A novel technology route of structure design and CNC machining for the integral impeller is proposed in this paper. Firstly, according to the relevant design criteria, the relevant parameters such as the overall impeller height, the blade height, the impeller inlet diameter, the impeller outlet diameter and the number of blades are obtained. Then the 3D model is created in the CAXA manufacturing engineer. Using CAXA CAM, the tool paths are generated in order to output CNC machining programs. The CNC machining programs are imported into the five-axis machining center for machining the integral impeller. The technology route can effectively improve the design efficiency, reduce the cost of design and manufacturing, and shorten the design cycle to a certain extent.

1. Introduction

Integral impeller is a key component of turbo engine, turbocharger and other power machinery, which is widely used in aerospace, fuel vehicles, petroleum machinery and other fields. The development of automotive engine supercharger technology is closely related to the development of high performance turbocharger. As a key component of turbocharger, integral impeller has an important impact on the performance of automotive engine supercharger system.

In recent years, the research on structural design and machining of integral impeller has made some progress[1]. Shi Wu et al. [2] proposed the theoretical model can be effectively optimized path of machining of integral impeller, which was tested by optimization experiments of working table posture. Wu Qiong et al. [3] proposed the cyclic symmetry analysis method was effectively used to improve efficiency and obtain more information of parameters for dynamic characteristic of integral impellers. Xinhong Xiong et al. [4] proposed the way to manufacture the superalloy double helix integral impeller using an approach of HPDM (hybrid plasma deposition and milling) which combines plasma deposition manufacturing as an additive technology and milling as a subtractive technique. However, some technical routes are rather complicated, and there are few studies on structural optimization design and processing of integral impeller using three-dimensional CAD/CAM software.



2. Structural Design of Integral Impeller

The gas output of turbocharger is mainly influenced by the pressure chamber, and the performance of compressor depends on whether the geometric design of impeller in the core is more reasonable. The optimization design of impeller geometric parameters is mainly considered from the energy.

The ratio of the inlet diameter D_1 to the outlet diameter D_2 of the impeller determines the flow of gas through the impeller. When the ratio is large, it means that the cross-section size difference between the inlet and outlet is small, which easily causes the separation of air flow and reduces the working efficiency of the compressor. The inlet diameter has a great influence on the gas flow. As shown in Figure 1, according to the relationship between the relative parameters in the velocity triangle, the ratio of the inlet diameter to the outlet diameter of the impeller can be deduced [5].

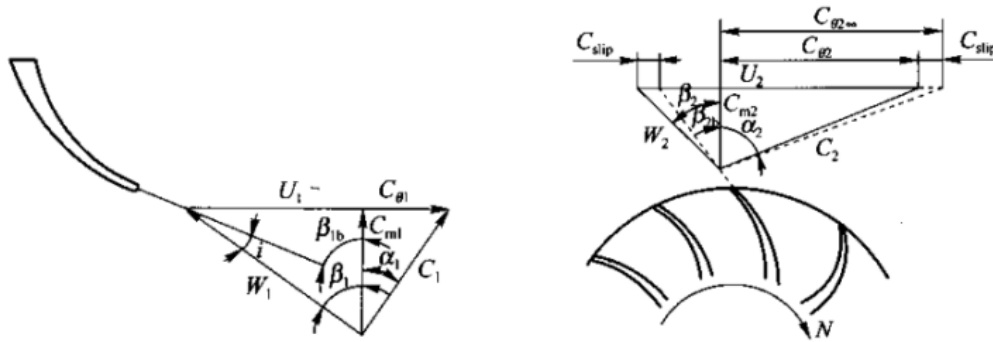


Figure 1. The velocity triangle of inlet and outlet for compressor impeller

From Figure 1, the ratio of inlet diameter to outlet diameter can be deduced as [5, 6]:

$$\left(\frac{D_1}{D_2} \right)_{W1_{min}}^2 = \frac{d^2}{D_2^2} + \sqrt[3]{2} \left[\frac{4\tau_2\rho_2 \frac{C_{m2}}{U_2} \frac{b_2}{D_2}}{\tau_1\rho_1} \right]^{2/3} \quad (1)$$

d is the diameter of impeller hub, τ_1 is the blocking coefficient of blade inlet, τ_2 is the blocking coefficient of blade outlet, ρ_1 is the density of inlet gas, ρ_2 is the density of outlet gas, b_2 is the width of blade outlet.

The number of blades affects the working load of impeller blades. If the number of blades is too small, the expansion angle and pressure gradient of the blade passage will increase. However, the increase will reduce the load on each blade, thus reducing the airflow deflection at the outlet of the blade. However, excessive number of blades will lead to friction loss of airflow and blockage of inlet, which will reduce work efficiency. The optimum number of blades depends on the structural angle of blade inlet and outlet and the ratio of impeller inlet and outlet diameter [7, 8].

After calculation, the height of impeller is 56.3 mm, the height of blade is 56.6 mm, the diameter of impeller inlet is 120 mm, the diameter of impeller outlet is 200 mm, the number of blades is 12, and the thickness of blade is 2 mm.

3. Modeling of Integral Impeller

Using CAXA manufacturing engineer (CAXA CAM) to model the optimized integral impeller is an efficient modeling and simulation method that can directly generate CNC machining simulations after generating three-dimension models.

The model of integral impeller based on CAXA manufacturing engineer requires the coordinates of each point of the impeller base and the blade surface contour, and the spline curve fitting is used to connect the coordinate points. The spline curve value point coordinates of the impeller base and the blade surface profile studied in this paper are shown in Table 1 and Table 2.

Table 1. Surface coordinates of impeller base

No.	X	Y	Z
1	30.000	0.000	60.000
2	30.022	0.000	56.016
3	30.695	0.000	47.667
4	30.408	0.000	31.105
5	48.201	0.000	16.966
6	77.151	0.000	6.464
7	100.000	0.000	5.000

Table 2. Boundary line coordinates of blade surface

No.	X ₁	Y ₁	Z ₁	X ₂	Y ₂	Z ₂
1	-100.000	0.000	5.000	-100.000	0.000	15.000
2	-92.356	-0.125	4.921	-95.661	-0.074	15.061
3	-78.340	-1.877	6.261	-86.614	-1.854	16.614
4	-54.564	-8.634	12.880	-57.020	-30.463	40.515
5	-32.036	-18.656	28.231	-32.148	-50.786	59.826
6	-9.178	-28.537	59.768	-	-	-
7	-9.088	-28.588	59.991	-	-	-

In CAXA manufacturing engineer, the impeller base surface is built according to the data in Table 1, and the model of the impeller base is generated. According to the data in Table 2, an impeller blade surface is established, and the other 11 impeller blade surfaces are generated using the annular array command, and the model of impeller blade is generated. Finally, the residual part of the tip of the impeller is cut by the surface cutting command to ensure that the impeller height meets the requirements. The complete three-dimension model of the integral impeller is shown in the figure 2.

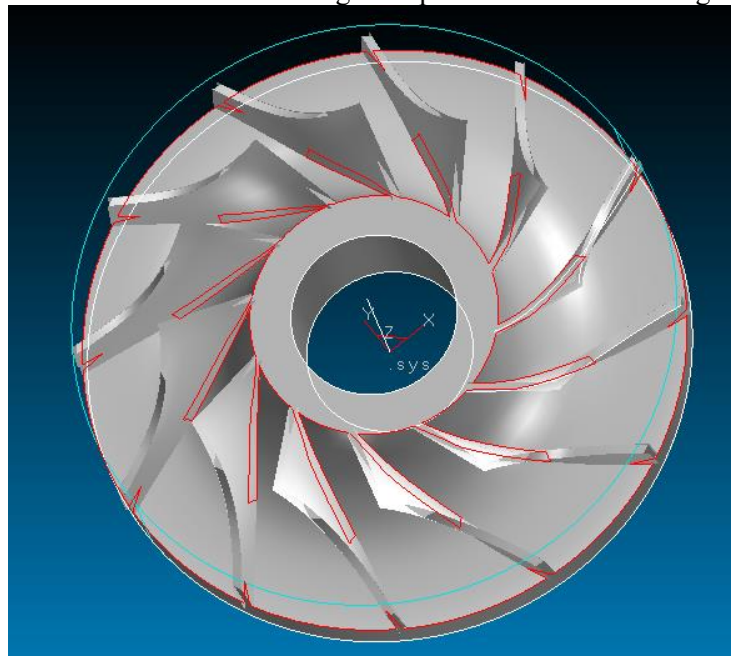


Figure 2. Three-dimension model of the integral impeller

4. CNC machining process of integral Impeller

The integral impeller has many blades with complex curved contour. Because the flow passage is deep and the arc diameter at the corner of the blade and flow passage runner is small, interference will easily

occur which will affect the machining quality and even cause tool breakage if the tool is not selected properly when machining flow passage of the integral impeller. The thickness of the blade is only 2 mm and its rigidity is poor, so the deformation of the blade is easy to occur during machining. Therefore, the selection of tools, the design of special jig and the design of processing technology route are very important in the CNC machining of integral impeller.

4.1 Design of special jig for machining the integral impeller

Since the five-axis CNC machining center is used to machine the integral impeller, it is only necessary to clamp the semifinished product at a time to directly from the semifinished product, and it is not necessary to repeatedly clamp the semifinished product. In addition, the overall impeller is a disc-shaped workpiece, and the residual material at the bottom of the blank is short, which is not suitable for ordinary jig for clamping. Since there is one through hole with a diameter of 30mm in the middle of the whole impeller, a special jig can be used for clamping. The special jig should have a certain degree of hardness, rigidity and high positioning accuracy without affecting the processing and measurement when clamping. According to the machining characteristics of the five-axis CNC machining center and the geometry of the impeller, a special jig is designed as shown in Figure 3. When clamping the semifinished product of impeller, the bolt passes through the through hole and is tightened together with the bottom worktable. At the same time, it can play the role of positioning reference in five directions. When the workpiece is clamped, the rotational positioning datum in Z-axis direction can be ensured by friction.

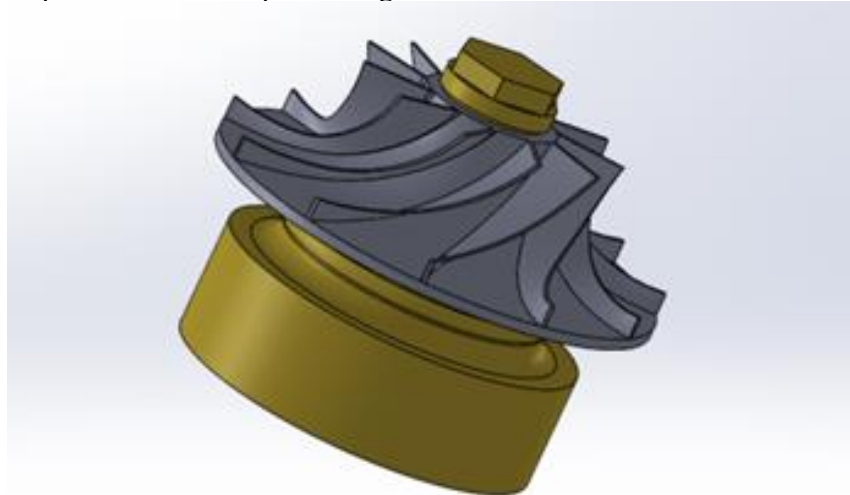


Figure 3. Special jig for machining the integral impeller

4.2 Design of processing technology route

In the processing of the flow path and the blade of the impeller, the rough machining and fine machining process route can be used to ensure the machining accuracy. Select a ball-end milling cutter with a diameter of 12 mm, and select a larger feed amount to rough the flow path and the blade first to reduce the length of time when the integral impeller is machined, and leave a certain machining allowance for fine machining. The ball-end ball cutter with a diameter of 8 mm is used for high-speed milling finishing, which not only ensures the surface quality and dimensional accuracy but also reduces the deformation caused by the blade during processing.

The CAXA manufacturing engineer develops a dedicated five-axis impeller roughing and fine machining module for the overall machining of the impeller, which greatly reduced the error caused by the impeller modeling and generating the tool path, and improved the production and processing efficiency. The impeller roughing module can rough the left and right sides and the bottom surface of the flow passage, and the fine machining module for impeller can finish the curved surfaces on both sides of the single blade. The tool paths of roughing impeller are shown in Figure 4. The tool paths of fine machining for impeller are shown in Figure 5.

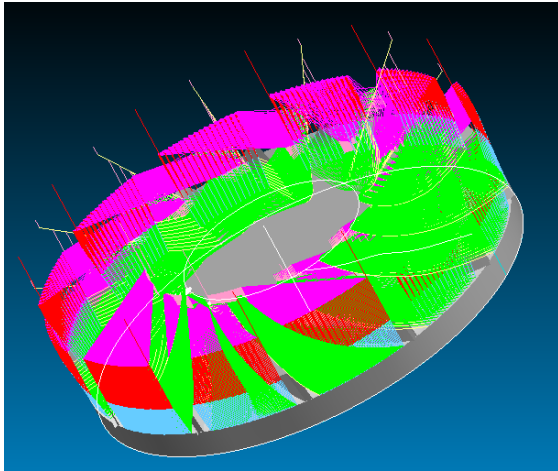


Figure 4. Tool paths of rough machining

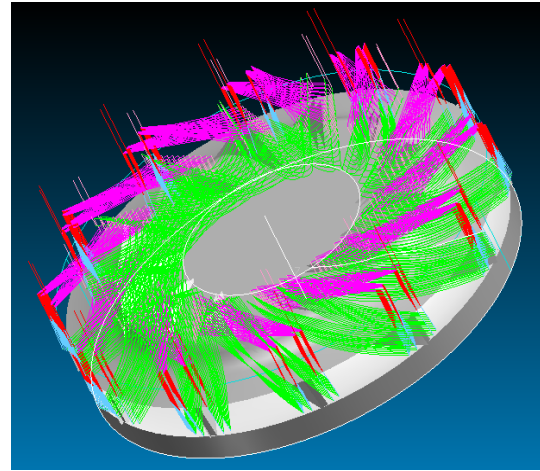


Figure 5. Tool paths of fine machining

4.3 Results of simulated CNC machining

The simulation results of rough machining and fine machining for the integral impeller using CAXA CAM are shown in Figure 6 and Figure 7 respectively.

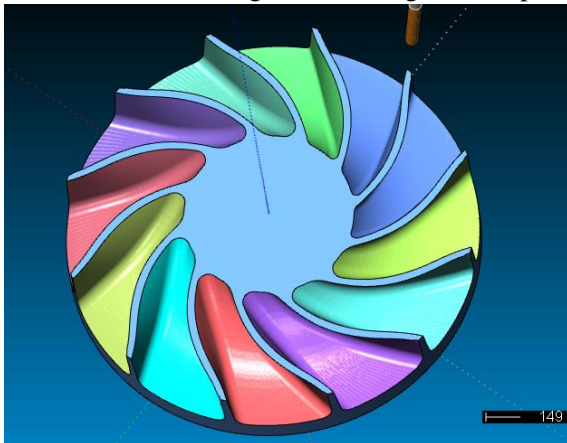


Figure 6. Simulation results of rough machining

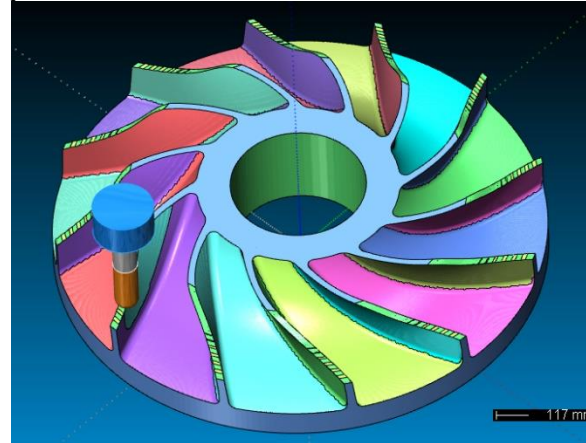


Figure 7. Simulation results of fine machining

4.4 Trial processing of integral impeller

The trial processing of the integral impeller is carried out at the five-axis machining center in the Numerical Control Technology Laboratory of Henan Institute of Science and Technology. Firstly, the five-axis machining center is equipped with corresponding high-speed milling cutters and special fixtures. Then the CNC machining programs generated by CAXA CAM are imported into the five-axis machining center to process the integral impeller using cast aluminum alloy. After a series of numerical control machining processes such as roughing and finishing, the integral impeller is processed. Measurements by the three-coordinate measuring instrument show that the dimensional accuracy of the processed impeller meets the technical requirements.

5. Conclusion

The technology route of structure design and CNC machining for the integral impeller proposed in this paper can effectively improve the design efficiency, reduce the cost of design and manufacturing, and shorten the design cycle to a certain extent.

Acknowledgments

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