Research of Integrated Impeller Modeling and Five-axis Machining Technology based on Reverse Engineering

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Abstract. Five-axis NC technology and reverse engineering provides critical support for industrial development and has been an important subject for scholars to study. This paper focused on aviation impeller and discussed the integrated application of NC machining technology and reverse engineering. It collected the shape point cloud data of the impeller through 3D scanner and Geomagic Wrap software and completed the reverse parametric modeling using Geomagic Design X software. The impeller model is complicated in structure which is hard to machine on three-axis and four-axis machine tools, hence developed a five-axis machining program by using the NC programming software of Hypermill and carried out actual machining test. The results showed that the error between the machined sample and the research model is less than 0.05 mm, which can satisfy engineering requirements. It also indicated that the NC program developed by Hypermill software has high machining accuracy and safety, and the integration of reverse engineering and five-axis technology presents positive significance to the innovative design and machining for complicated engineering surfaces.

1. Introduction
With the development of industrial technology, significant progress has been made in the theories regarding NC technology and reverse engineering. As one of the newest NC technologies, five-axis machining technology has been widely applied in multiple industries such as aviation, aerospace, and automobiles [1,2]. It represents the level of a country’s advanced manufacturing technology and provides support for their industrial development. Five-axis machine tool is featured with strong machining capacity and complicated structure [3,4]. It can complete multiple machining processes at one clamping, thus improving the machining quality, reducing the clamping error and fulfilling the machining of complicated parts efficiently and accurately [5]. But it also raises high requirements for the accuracy of programs. Therefore, the study of the accuracy of the program designed for the machining of complicated parts of five-axis NC machine tool and its test method is of great importance to the popularization and application of the five-axis machine tool.

Reverse engineering technology, also known as reverse design technology, uses digital scanning equipment (such as laser scanner) to obtain the shape parameters of an object [6-8], and then transforms the parameters into a digitized model. As one of the critical methods of advanced manufacturing technology, reverse engineering technology applies to the modeling of any parts and is critical for the modeling and innovative design of complicated parts.
The research on the new theory and method of NC machining technology and reverse engineering is closely related to modern design method and manufacturing technology [9,10]. It is also one of the important means to develop intelligent manufacturing technology and has positive significance to promote the development of industrialization [11,12]. Thus, the study of reverse engineering and five-axis machining technology is important for the promotion of industrialization process.

Impeller is a key part for modern mechanical power installations such as aero-engine, turbocharger, and compressor, etc. It consists of impeller blades and the hub. The blades have a warped surface which makes the structure of the impeller complicated and hard to machine. Tool path is complicated and usually has the problems of blade collision, tool tipping and local defects, which seriously affects the machining accuracy of the impeller. This paper focused on impeller and established the parametric model by using reverse engineering technology. Then Hypermill NC programming and simulation software was applied to write the five-axis machining program, and the machining test with the program was conducted. The findings of this study are expected to provide theoretical basis for designing complicated parts and developing machining technology, and promoting the integrated development of reverse engineering and five-axis NC technologies.

2. Materials and Methods

2.1. Test materials

This paper takes aviation impeller as its studying object. The instruments and equipment include Win3D scanner, point cloud parameterization and surface packaging software Geomagic Wrap, reverse modeling software Geomagic Design X, NC programming software Hypermill, TR200 surfagauge, Mikron HEM 500U five-axis machining center, CONTURA G2 three coordinates measuring instrument, various types of milling cutters, tool handles, and aluminum alloy bars with different diameters.

2.2. Test methods

Note: a and b represent the two states of impeller during scanning process

Figure 1. Reverse scanning of impeller

Figure 2. Reverse parametric model of impeller
2.2.1. Establishment of parametric model. Preparation: Adjust the working state and relevant parameters of the Win3D scanner; set the collection error at 0.02 mm based on the accuracy of the model; spray powder on the impeller and arrange the marking points (Figure 1). Collection of model data: put the impeller model with marking points on the calibration plate at the lower part of the scanner; use 3D scanner to collect the structural point cloud data of the impeller model; apply Geomagic Wrap to make parametric processing of the point cloud data, encapsulate them into the blade model of the impeller, and save in *.stl format; import the *.stl blade model into Geomagic Design X software for solid parameter modeling (Figure 2); export the solid model in the 3D universal format of *.stp for later programming and simulation in Hypermill software.

2.2.2. NC programming. Proper sized aluminum bars were selected as machining blanks for NC programming. The complicated structure of the model makes it hard to perform the machining with three-axis or four-axis NC machining center. Therefore, this paper employed stronger five-axis NC machining center (MIikron HEM 500U) to perform the machining test. Five-axis machine tool has high machining accuracy as well as more complicated structure. To ensure the safety of the machine tool and avoid damages caused by blade collision, five-axis machine tool raised higher requirements in the accuracy of the program. This study applied Hypermill software to write the NC machining program of impeller using the following method: import the impeller model file in *.stp format into Hypermill software for NC programming and proceed virtual machining. The cutting path of the virtually machined tool coincided exactly with that of the actually machined tool.

Considering the complicated structure of impeller, the machining of it can be divided into different steps as shown in Figure 3. The main process includes rough machining, semi-finish machining and finish machining. The machining of blades was completed in three steps: trailing edge machining, rough and semi-finish machining and finish machining. Rough machining was conducted with fixed axis machining, i.e. the four-axis machining, which keeps the B axis non-rotating and the basic shape was roughly machined by the end-milling cutter. The trailing edge machining of blade was also conducted by fixed axis machining, in which the finish machining of this curved surfaces were completed by ball-end cutter. The rough machining, corner cleaning and fine machining of blade and path were all performed by five-axis machining, with the ball-end cutter rapidly cutting tiny surfaces (low feed and high speed) to complete the machining of the impeller model. After inspecting the corresponding programs of each work procedure, Hypermill program was used for post processing to generate machine tool processing code for actual machine tool processing.

![Figure 3. Machining process of impeller](image)

2.2.3. Machining test. The integration performance of reverse design and five-axis machining can be verified by comparing the size and shape errors between the machined impeller and the impeller model. For this reason, a five-axis machining test of impeller was carried out on Dec. 23, 2020 at the Intelligent
Manufacturing Training Center of Shaanxi Institute of Technology. Before the test, the cutters, spacers, fixtures and other tools required were prepared. First turn on the Mikron HEM 500U five-axis NC machining center (B axis, C axis and cradle machine tool) and preheat for 10 min. Meanwhile, adjust the rotation angle of the B and C axis of the machine tool to 0°, translate the X, Y and Z axis to the position above the middle of the forward stroke and complete the blank clamping. Then, import NC program into the machine tool control system, install all the cutters into respective tool magazines, and finish the tool setting. Start the machining test, read the machining program and enable the automatic machining. The machining of the impeller model can be completed with one clamping, as shown in Figure 4. After machining, the shape and size errors between the machined impeller model and the reverse test model were determined using CONTURA G2 three coordinates measuring instrument. The results showed that the maximum error is less than 0.05 mm. Then TR200 surfagauge was used to test the surface quality. The result indicates that the roughness has reached Ra3.2, which can meet the requirements of dimensional accuracy and surface quality in engineering.

![Figure 4. Machining site](image)

3. Results and Discussions

3.1. Reverse modeling analysis
Reverse modeling is to establish a digitized model of an object by means of parameterization. It can be seen by comparing Figure 1 and Figure 2 that reverse modeling method can perfectly replicate complicated models. This reverse model can be re-designed in Geomagic Design X software. This process mainly relies on 3D scanner to collect the shape point cloud data of the model, and its efficiency and accuracy are much higher than traditional three coordinates measuring methods. Therefore, reverse design method has become a major direction of future innovative designs for complicated models.

3.2. Hypermill NC programming analysis
The specific machining position of the tool, the quality of the machining surface and the processing time required can be obtained based on the characteristics of tool path and the NC program code generated in real time by HyperMill software. It can be also determined whether the program is reasonable and efficient. The NC program and machining results indicate that the surface quality of the machined impeller model can satisfy design requirement, and the Hypermill NC programming method can effectively process the tool path of complicated parts and avoid over-cutting, interference and residual problems during five-axis machining, thus improving the machining efficiency and safety production of complicated workpieces.

3.3. Reverse modeling and five-axis machining analysis
The parametric model of impeller was established by reverse modeling and was machined by five-axis machining technology at one time to avoid the error caused by multiple clamping. By comparing the error between the machined sample and the research model (the maximum error is 0.06 mm), it can be
inferred that the integration of reverse engineering and five-axis technology can achieve high-quality product innovative design. Considering the actual production, the rough machining and semi-finish machining can be conducted on low accuracy machine tool so that to leave space for the five-axis machining, reduce the mechanical loss during rough machining, and maintain the accuracy of the machine tool as long as possible. The research is of great significance for the promotion of industrialization process.

4. Conclusions
Reverse modeling and five axis machining test of aviation impeller were carried out in this paper to investigate the reverse design method and machining technology of impeller. The results showed that the error between the machined sample and research model was less than 0.06 mm, which can satisfy engineering requirements. Meanwhile, the five-axis NC program developed by Hypermill software shows high accuracy and safety in machining complicated curved surfaces. Therefore, the integration of reverse engineering and five-axis technology is of great significance in improving the innovative design of complicated curved surfaces in engineering practices, enhancing the innovation ability of enterprises, and promoting the industrialization progress.

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