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Study of applying reverse engineering to turbine blade manufacture

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Abstract

A turbine blade has complex shaped free-form surfaces that can be modelled as surfaces with variable curvature by high-degree polynomials. Industry typically utilizes a turnkey system and special-purpose machine tool to manufacture turbine blades. A turkey system is a closed form design. Users need only input relevant data to this system to manufacture the product directly. However, users are unaware of the internal operation of the system. With rapidly advances in computing technology, commercial CAD/CAM systems can be utilized to design freeform surfaces and generate a tool path for the designed surfaces. This study uses a reverse engineering technology that is used to reconstruct the CAD model for a turbine blade. The prototype is measured by a coordinate measuring machine to obtain the geometrical control data points that are used to generate the CAD model in the UniGraphics (UG) CAD/CAM system. The UG/GRIP (GRaphics Interactive Programming) language is used to generate the cutter location data rather than using the default UG CAM module. A five-axis NC code is acquired by the developed postprocessor and verified by the solid cutting simulation software VERICUT®. Real turbine blade machining is performed on a table/spindle tilting five-axis machine tool, demonstrating the effectiveness of the proposed approach.

Keywords: Reverse engineering; Coordinate measuring machine; Turbine blade; Five-axis

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1. Introduction

With the development of computer technology, CAD/CAM system is widely applied to die making, astronautics and precision machining industries. This study discusses CAM technology used for centrifugal turbine blades in steam turbines and air compressors. The steam turbines in power plants, for example, have complex blade geometries that affect steam turbines performance, but also yield vibration or erosion, and even damage during prolonged interactions between components and fluids. Furthermore, most of imported steam turbines or air compressors sets are fitted with expensive and complex blades.

Generally, most blade manufacturers use a turnkey system and special-purpose machine tools when producing blades. Users are only required to enter the relevant design parameters to construct the blade models and generate NC program directly. Due to the extremely complex geometric shape of blades and the inaccessibility of the original design data, when blades are damaged, the downstream power plants must shutdown for 3–4 months, and in some cases up to 6 months as they wait for an imported blade. Using reverse engineering technology is a feasible method of manufacturing blades that reduces costs and facilitates rapid blade replacement. Reverse engineering technology is a CAD modeling technology based on actual object reconstruction, which is typically applied to the engineering with actual models and without an original CAD model. Measurement and curve reconstruction technology is utilized to construct CAD models, then CAM tech-

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nology is applied to determine the tool path and NC program. The finished products are finally processed using NC machine tools.

This study uses reverse engineering technology and a coordinate measuring machine to measure the blade points. Blade CAD models are reconstructed using commercial software (UniGraphics, UG). Some studies [1, 2] have focused on blade processing and manufacturing through CAD/CAM. However, this paper presents an approach for generating cutter location data by a user-defined program written in UG/GRIP (GRaphics Interactive Programming) language [3] instead of using the default UG CAM module. Compared with traditional methods, the proposed method can acquire a uniform processing surface, reduce machining time and improve manufacturing efficiency. A five-axis NC code is obtained by the developed postprocessor and verified using the solid cutting simulation software VERICUT® [4]. Real machining of a blade disk on a table/spindle tilting five-axis machine tool verifies the effectiveness of the proposed scheme.

2. Geometric characteristics of blade disks

The centrifugal compressor blade disk is divided into hub and blade, in which the hub is composed of hub surfaces that form a hub curve around the coordinate central axis. The hub curve is typically obtained from preliminary computation of aerodynamics and hydrodynamics, which are then substituted into an optimization algorithm. The blade is composed of suction surface, pressure surface and leading edge (Fig. 1). The shroud surface, generated from the shroud curved around the coordinate central axis, is primarily applied to control the compressor blade disk profile.

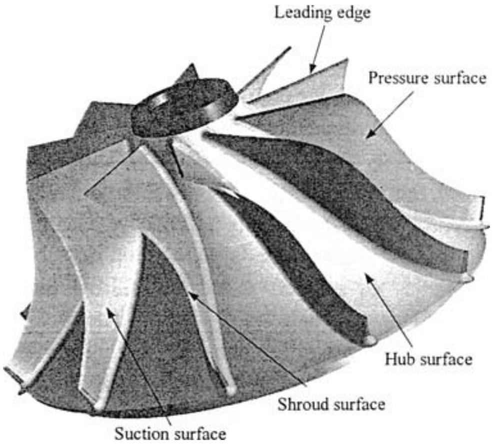
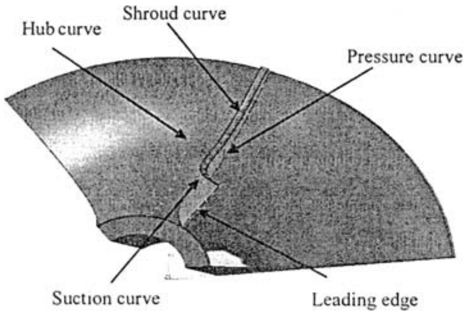


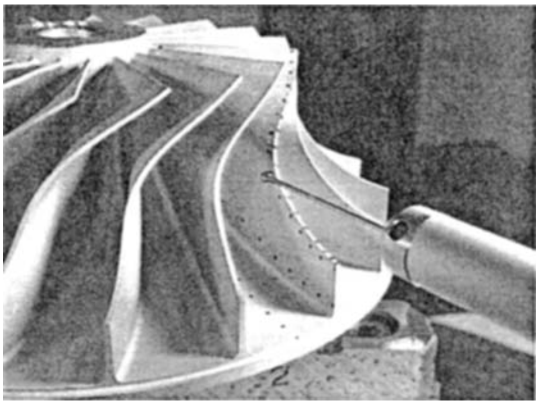
Fig. 1. Geometric characteristics of blade disk.

3. Determination of measuring path

The characteristic points of a blade disk are measured using a ZEISS RPISMO7 coordinate measuring machine. Fig. 2(a) shows a schematic diagram for measuring the geometrical control data points of a blade disk. Measurement points are marked onto the blade profile using a painting pen. The blade profile characteristics comprise 5 measurement zones, of which a hub curve and shroud curve are only required for planning of a single curve measurement zone, a pressure surface and suction surface for planning of two curve measurement zones, and a leading edge that only requires measurement of 4–5 points at the highest locations along the edge. The number of measurement points for each zone is determined when necessary; however efforts are



(a) inspection points



(b) measurement of suction curve

Fig. 2. Schematic diagram of inspection points of blade disk on different zones and real measurement.

made to obtain a balance point with respect to cost, time and demand. Owing to the torsional characteristic of a blade curve, measuring the shroud position near the leading edge and hub surface is difficult, consequently, the probe is adjusted several times to measure the blade profile correctly. This procedure is complex and time-consuming. Fig. 2(b) presents the procedure for measuring a suction curve.

4. Geometric modelling of blade disks

The measurement points from hub, shroud and leading edge curves are imported into UG software, whereby the hub and shroud curves are constructed using the 'fit' function of a spline curve, and the leading edge is constructed linearly. Based on these curves, the geometric models of blade disk stock can be obtained by rotating 360° around the central axis.

The entire blade disk is composed of 16 blades. Once the geometric model of a single blade is established, a complete blade disk model can be obtained by duplicating and rotating a single blade by 22.5° along the central axis. The pressure surface and suction surface are two major curves on a blade. During actual measurement, two characteristic curves are measured from individual surfaces (pressure surface and suction surface), i.e., pressure curves 1 and 2, suction curves 1 and 2. The measurement points on the characteristic curves are first entered into UG software, the characteristic curves can be constructed using a 'through point' function of the spline curve. Then, with the 'ruled surface' function, the pressure surface is obtained by selecting pressure curves 1 and 2. Similarly, the suction surface is obtained by selecting suction curves 1 and 2. Furthermore, these two curves are extended to obtain the actual pressure curve and suction curve by using 'intersect' and 'curve smooth' functions based on blade disk models. Actual pressure surface and suction surface can then be constructed using the 'ruled surface' function. Finally, with the 'through curves mesh' function, the offset surface between the pressure surface and suction surface can be generated to obtain a single blade. Fig. 3 shows the single blade and hub surfaces combined.

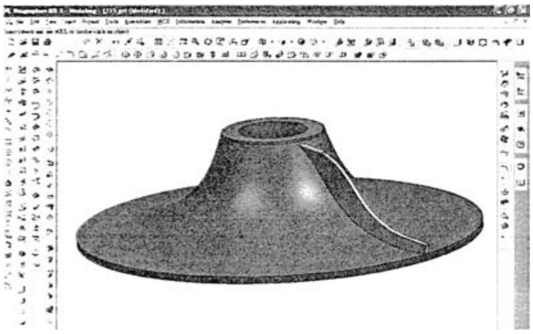


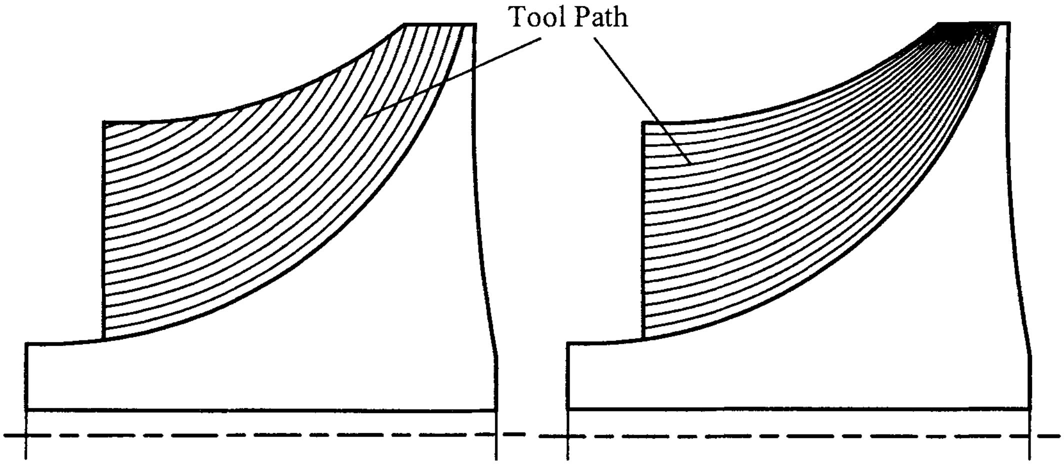
Fig. 3. Combination of created single blade surface and hub surface.

5. Tool path and NC generation

Once the CAD model of the blade has been created, the CAM module should be adopted to generate the appropriate tool path, which is further post-processed to the required NC code. To increase the cutting efficiency and flexibility, UG/GRIP language was used to create the tool path rather than using the default UG CAM module. The GRIP provides a facility for writing interpreted programs in a UG programming language, and customization capabilities of UG to automate tool path creation and file management functions. This reduces process planning time, and also ensures manufacturing standardization. The process planning of the blade disk consists of rough, semi-finish and finish milling of the blade (pressure surface, suction surface, leading edge) and a hub surface. The main steps involved in the GRIP are as follows:

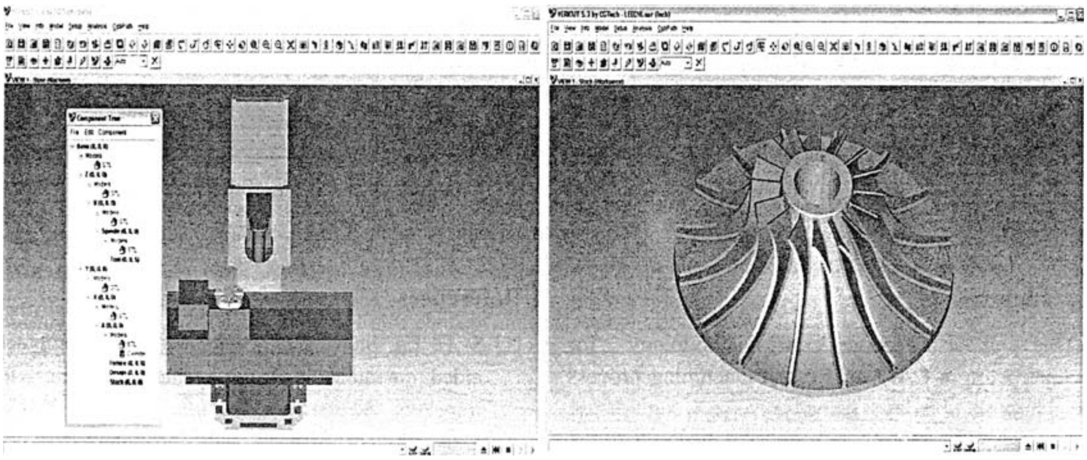
1. Specify the part geometry of the pressure surface, suction surface, leading edge and hub surface.
2. Input cutting data, such as cutter definition, machining type (e.g., zigzag, and planar mill), cut step, spindle speed, and feed rate.
3. Call subroutines to generate a cutter location file (CLSF file)
4. Output the CLSF file

Compared with the conventional UG CAM module, the tool path generated by the developed GRIP program (Fig. 4) not only obtains a smooth blade surface, but also shortens the machining time, and, hence, increases machining efficiency. The generic multi-axis postprocessor system proposed by the authors [5, 6] is used to convert CLSF file into machine control data (NC code). The NC data depends on the configuration of the machine tool employed. In this study, the five-axis machine tool (Bosto Matic 505) with a spindle rotary axis (B axis) and table rotary axis (C axis) is employed to machine the blade disk.



(a) tool path generated by GRIP (b) tool path generated by conventional CAM module

Fig. 4. Comparison of tool path generation.



(a) kinematics model of the machine tool (b) final shape of the simulated blade disk

Fig. 5. VERICUT® simulation of the blade machining.

6. VERICUT® simulation

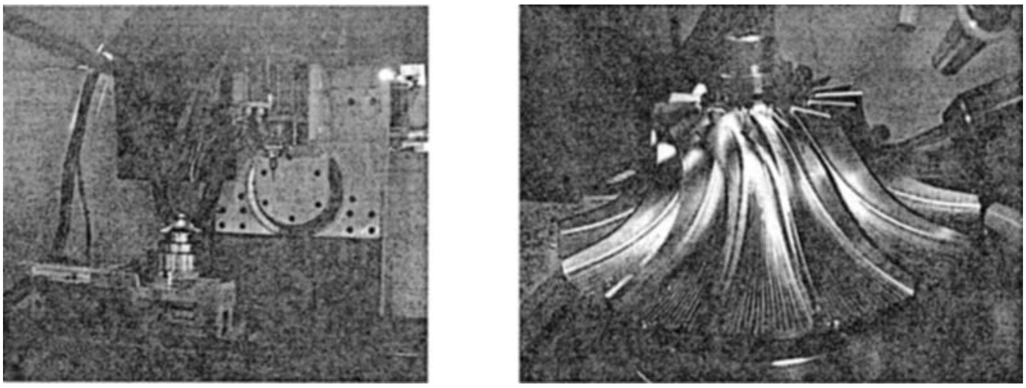
As five-axis machining has two additional rotary movements, detecting the collisions between all machine tool components, such as rotary tables, rotary spindles, fixtures, work pieces, tool holders and cutting tools, is essential. To eliminate risk of programming error, the generated five-axis NC data are confirmed using the solid cutting simulation software VERICUT®. Through the construction of the kinematics model of an NC machine tool, a realistic 3D simulation of the dedicated CNC machine was generated. Fig. 5 shows the kinematics model of the configured machine tool and final shape of the blade disk machined on the five-axis machine tool.

7. Experimental implementation

A trial-cut experiment was conducted to confirm the feasibility of the developed methodology. A stainless raw material was first cut using a CNC lathe machine, and then machined on the five-axis machine tool for rough, semi-finish and finish milling operations. Table 1 presents machining parameters for each step. Fig. 6 shows the five-axis machine tool used and finish milling of the blade, demonstrating that the proposed methodology can be successfully applied to practical turbine blade machining.

Table 1. Machining parameters for blade disk.

Operation	Blade disk roughing	Blade semi-finish	Hub semi-finish	Blade finish	Hub finish
Spindle speed (RPM)	5000	7500	7500	9000	9000
Feedrate(mm/min)	310	460	460	640	640
Chip load per tooth (mm)	4	0.2	0.2	0.1	0.1
Allowance (mm)	0.3	0.1	0.1	0	0
Cutting tool (ball mill)	$\phi 8$	$\phi 4$	$\phi 4$	$\phi 4$	$\phi 4$
Machining time (min)	150	112	80	200	192



(a) five-axis machine tool employed (b) finish milling of the blade

Fig. 6. Real machining experiment.

8. Conclusion

This paper proposes a methodology for reconstructing a CAD model and machining process for turbine blades using reverse engineering technology. The geometrical control data points of the prototype are measured on a coordinate measuring machine and imported into UG to create the CAD model. Cutter location data are obtained by the developed UG/GRIP program and post-processed to the actual NC code. Through the verification on the solid cutting simulation software and a real machining experiment, it demonstrated the effectiveness of the proposed scheme, which can also be applied to other products with complex shapes.

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