

Critical Technologies for Development of Turbine Blade Design Inspection & Integration Software

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Abstract. Unstable design quality, absence of design and processing assessment tools, and insufficient development software and engineering data management method have already emerged as projecting problems in practical turbine blade design work. The paper proposes blade model inspection scheme based on profile waviness adjustment algorithm, and developed turbine blade design and processing quality assessment add-ins based on secondary development of UG software. All these add-in modules as well as some commercial software are integrated in ANSYS Workbench for unified management of design flow and sharing of engineering data in ANSYS Workbench. The obtained tools are applied into practical turbine blade design workflow and helped the reduction of manual labour.

1. Introduction

The surface of the aero-engine turbine blade is a complex free-form surface. The surface with good smoothness can reduce the difficulty for manufacturing process, simplify processing scenarios cut down manufacturing cost [1]. And the surface quality, which is a direct reflection for the quality of blade's final geometry, has great impact on its performance [2]. So in the blade design work, it's important to guarantee the design data fully exploited by manufacturing process, and export smooth surface for the downstream analysis as well as CAM process, thus reduce the possible labour caused by extra communication between design and manufacturing department, which tends to arise when the blade geometry data cannot be used in machining.

Based on the survey work by authors, the existing turbine blade design process has the following problems at present: the design flow is complicated and not unified, involving numbers of designers and tools. The primary design results often need corrections, but these corrections and further inspections heavily rely on manual operation, resulting in turbine blade design's unstable quality. What's more, turbine blade design is a multi-disciplinary process involving industrial software aimed at different problems, the integral application of these software requires standard design specifications and unified design data management [3], which is also in shortage for real work.

Therefore the development of specialized software tools for turbine blade automatic adjustment and quality assessment, as well as software integration can make up for the shortcomings in current work. This scheme can integrate the actual turbine blades' design flow to achieve the solidification of turbine blade design processing and the unified management of engineering data, on the basis of standard quality assessing methods and uniform model correction tools, the design result can reach consistent quality. This paper is addressing this problem and offer an overall technology approach for improving the current turbine blade design process. The essentials of our work can be divided into the following three parts: automatic adjustment of the blade profile, design and processing quality assessment, and turbine blade design as well as quality assessment environment integration.



2. Turbine Blade Profile Adjustment

The turbine blade profile curve can be generated by interpolating the blade profile coordinate data in the UG software. The blade profile coordinate data only contains the position information of the discrete blade profile, and lacks the definition of the parameterization method. The unqualified interpolation curve parameterization method will cause the newly generated blade profile spline to have waviness, which can be judged by the curvature vector distribution of the resulting profile spline, as shown in figure 1. The blade profile spline is used to construct key aerodynamic surfaces whose waviness will increase the energy consumption and degrade the performance of the engine. In the traditional design process, the designer's manual work is needed to adjust the position of the profile spline's interpolation point to eliminate the waviness, making turbine blade design model with uncertainty of the result and often need extra rework.

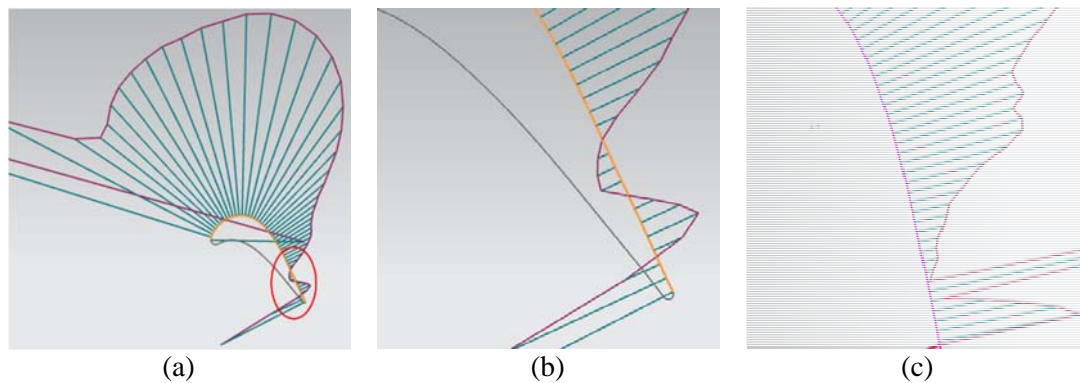


Figure 1. Contrast figure before and after manual adjustment of blade profile spline waviness

To handle this situation, we have developed automatic adjustment method of blade profile spline, it is based on the convexity preserving property of NURBS curves [4], which analyses the distribution of the curvature of blade profile spline, and adjusts the control polygon of blade profile spline to make it convex, thus achieving automatic elimination of blade profile spline waviness. The specific workflow is as follows:

- According to the blade profile coordinate data, the interpolation spline is calculated by using the chord-length parameterization method.
- Determine the sampling point density according to the length of the spline, calculate the curvature vector at the sampling point, as in equation (3), and judge whether the direction of the curvature vector of each sampling point satisfies the non-waviness condition. As in equation (1), P_i is a control vertex whose index value is i , k represents a k -th derivative, p is spline's degree, and u_i represents a knot node vector node whose index value is i . As in equation (3), $N_{i,p-k}(u)$ is a $p-k$ -degree B-spline basis function with an index value of i at the parameter u , and $C^{(k)}(u)$ is the k -th order of the spline at the parameter value u [5].

$$P_i^{(0)} = P_i, k = 0; P_i^{(k)} = \frac{p-k+1}{u_{i+p+1}-u_{i+k}} (P_{i+1}^{(k-1)} - P_i^{(k-1)}), k > 0 \quad (1)$$

$$C(u) = C^{(0)}(u) = \sum_{i=0}^n N_{i,p}(u) P_i^{(0)} \quad (2)$$

$$C^{(k)}(u) = N_{i,p-k}(u) P_i^{(k)} \quad (3)$$

- The control vertices near the abnormal curvature vector are adjusted along the curvature vector direction to satisfy the control polygon convexity preservation condition. The new control vertices are used to construct the profile spline, as shown in figure 2. The blade profile spline is interpolated at 99 points, the maximum adjustment distance at the trailing edge of the profile spline is 0.02083 mm, and the number of adjusted control vertices is 26.

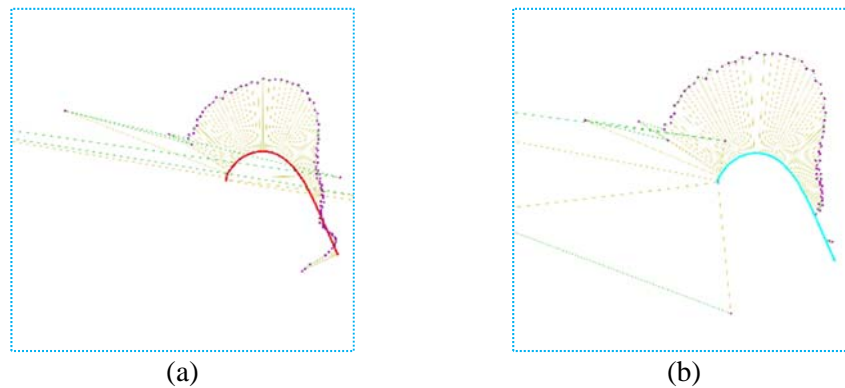


Figure 2. Contrast figure before and after the automatic adjustment of blade profile spline waviness.

3. Turbine Blade Design and Processing Quality Assessment

The quality assessment of turbine blades consists of turbine blade design model surface quality assessment and surface processing quality assessment. Traditional design model surface quality assessment methods include curvature analysis method, illumination method and contour analysis method, etc. [6], which are used to obtain the inflection point of turbine blade body section, the concave-convex distribution and the shape change of the surface. These methods are intuitive but lack quantitative results, and leaves further work unclear to deploy. Turbine blade processing quality assessment generally uses three coordinate measuring instrument or optical scanning system to obtain measurement data, and the measurement data can be imported into UG software to compare with the design model to calculate the shape and position error, while there is a lack of unified method for evaluating the surface waviness of turbine blade. In workshop the blade design and processing quality assessment process relies on the experiences of the workers, to provide standard tools and methods for the assessment is the pursuit of practical work for increasing the competence. So in our work we developed the turbine blade quality assessment tools based on secondary development of UG software.

3.1. Design Quality Assessment Method

The assessment of turbine blade design quality work is mainly by the calculation of blade surface waviness. Based on the UG/Open API library, a specialized add-in for surface waviness assessment of turbine blade model was developed, which is used to extract and quantify the fluctuation information of turbine blade surface to transform the assessment rules into an objective manner.

The specialized software extracts the section information of the blade body in two orthogonal directions, and uses the curvature analysis method to calculate the inflection point information of turbine blade profile (see figure 3) and the stacking curves (see figure 4) based on the curvature vector distribution. The position and number of spline inflection points of the turbine blade profile and turbine blade stacking curves are output as the assessment result of the model design quality.

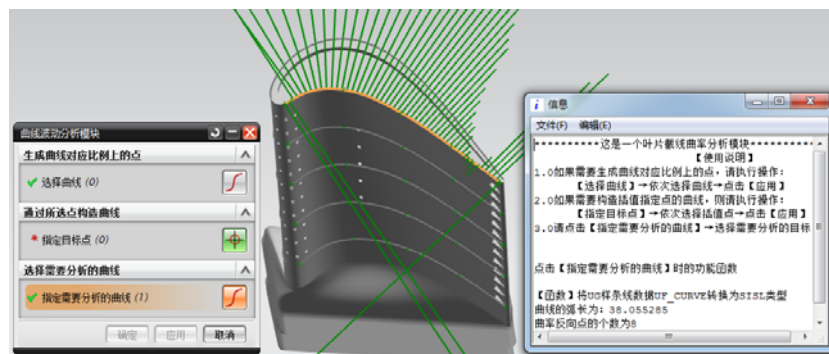


Figure 3. Assessment of turbine blade profiles.

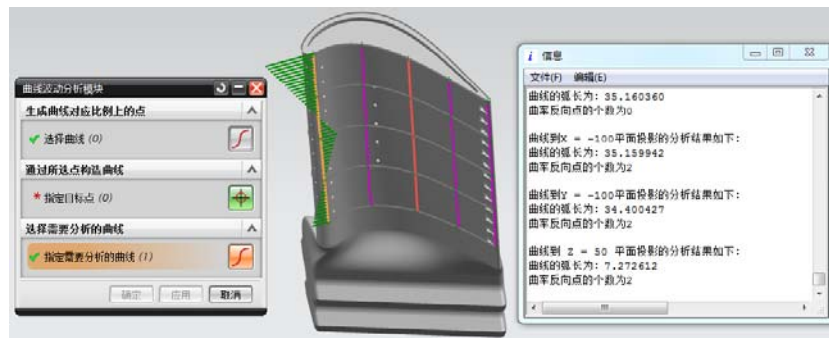


Figure 4. Assessment of turbine blade stacking curves.

In addition, based on the UG/Open API library, the feature parameter extraction specialized for the blade model is developed, and the turbine blade gravity centre parameter and the centre parameters of each section of turbine blade can be extracted, as shown in figure 5. These functions can further help to find the problems in the design model.

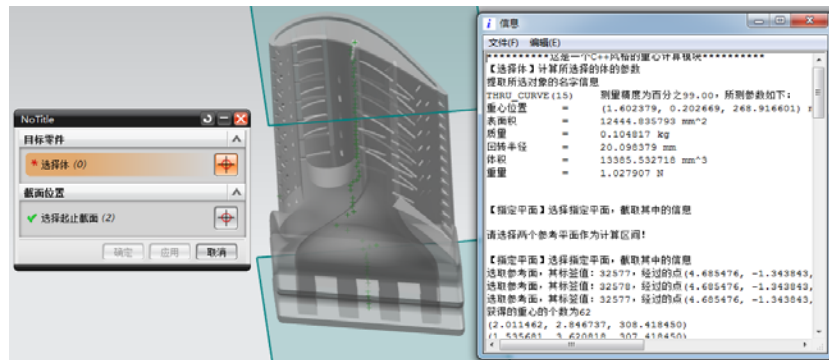


Figure 5. Turbine blade centre of gravity and central parameters of each section.

3.2. Processing Quality Assessment Method

The assessment of turbine blade processing quality work is mainly by the calculation of the surface waviness parameters. The raw processing data is measured by a coordinate measuring machine and the coordinate registration work is not considered in this paper. Based on the UG/Open API library, blade processing quality assessment tool is developed. In the UG environment, the deviation information between the coordinate measured and the turbine blade CAD model can be compared, and the surface's waviness can thus be revealed. This function is realized by calculating the relative distances between the measurement data picked up by the user and the theoretical blade profile spline according to the blade section profile. In the calculation process, we get X_i which is the nearest point to P_i on theoretical blade profile spline (see figure 6), and d_i which is the signed distance between X_i and P_i . The sign of d_i represents the relative position between P_i and theoretical blade profile spline. The arc length corresponding to X_i is obtained as l_i .

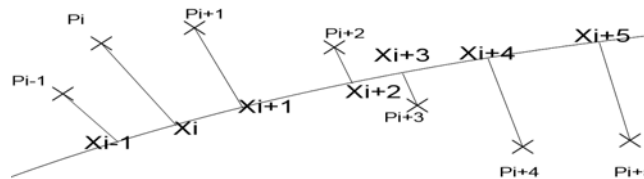


Figure 6. Arc length and relative distance calculation.

We take l_i as abscissa and d_i as the ordinate, and fit those coordinates (l_i, d_i) with B-spline which is used to calculate the inflection points I0, I1, I2, etc. (see figure 7). The absolute value of the d -

coordinate and l -coordinate difference between the adjacent inflection points are taken as the amplitude and wavelength of the waviness. The ratio of the amplitude to the wavelength is calculated as the change rate of the waviness, and the fluctuation of the output wavelength between 1 millimetre and 10 millimetre is considered as the waviness information.

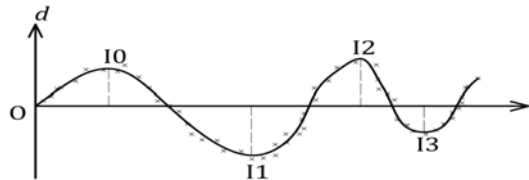


Figure 7. Waviness amplitude and wavelength calculation

As is shown in figure 8, the processing quality assessment data is 392 points.

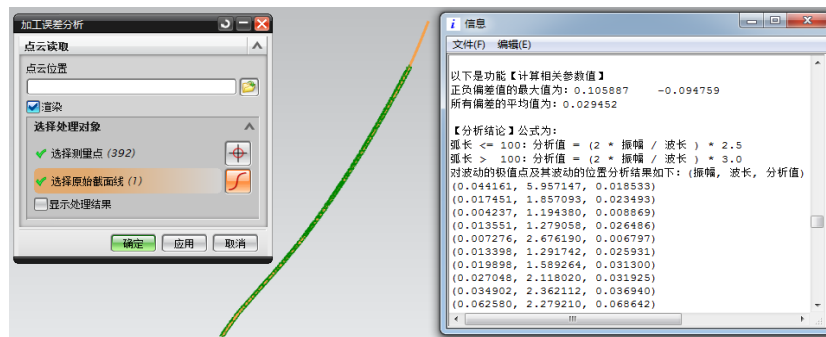


Figure 8. Blade processing quality assessment

4. Turbine Blade Design and Quality Assessment Environment Integration

Turbine blade design results can be obtained from a sequential engineering or reverse engineering workflow. A variety of software maybe used, such as UG(for design), Geomagic(for point cloud processing), ANSYS(for performance analysis) and so on. The real work process can be very complex and much work is devoted to the data conversion in different software or the function shift between different platforms. In order to regulate the work process and coordinate the software tools, we use ANSYS workbench as the basis for integrating cooperation of different software and manage the overall dataflow. The workflow of each software module and the data file management logic are shown in figure 9.

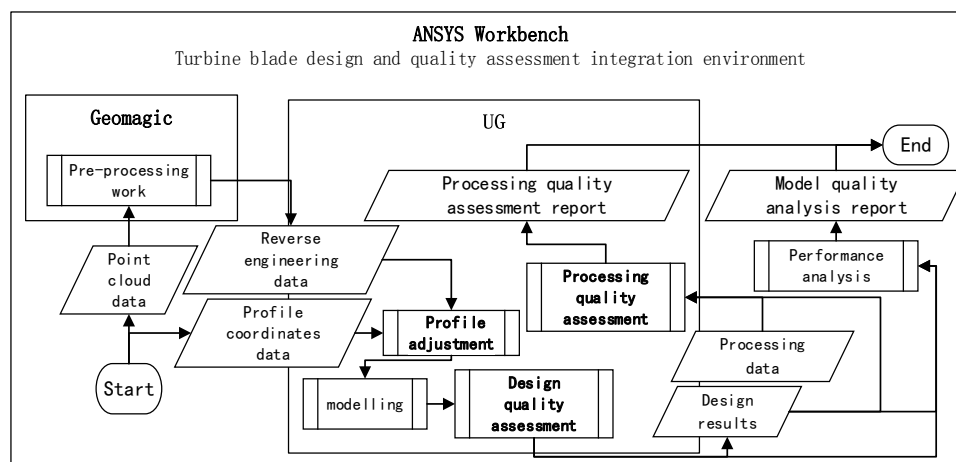


Figure 9. Turbine blade modelling and testing standardization process

During the reverse engineering step, the designer first enable the Geomagic by Workbench to complete the pre-processing work from the turbine blade point cloud data, and the output data from Geomagic will be automatically transmitted to UG. After the data has entering the UG, the user adjusts the blade profile spline waviness by adopting the blade profile spline waviness correction add-in, and completes the blade modelling work, generating the model quality analysis report and turbine blade CAD model that meets design requirements. The turbine blade model data output by UG will be automatically transferred to the ANSYS simulation analysis software, and the user can complete the simulation analysis there. After completing the machining of the turbine blade parts, the user can compare the deviation of the part processing measurement data with the CAD model in UG, and output the blade processing quality assessment report through the blade processing quality assessment tool. Based on the secondary development of ANSYS Workbench, the development of turbine blade design environment integration tools is realized. The workflow and file management of the relevant software is customized using XML and Iron Python. The module operation is shown in figure 10.

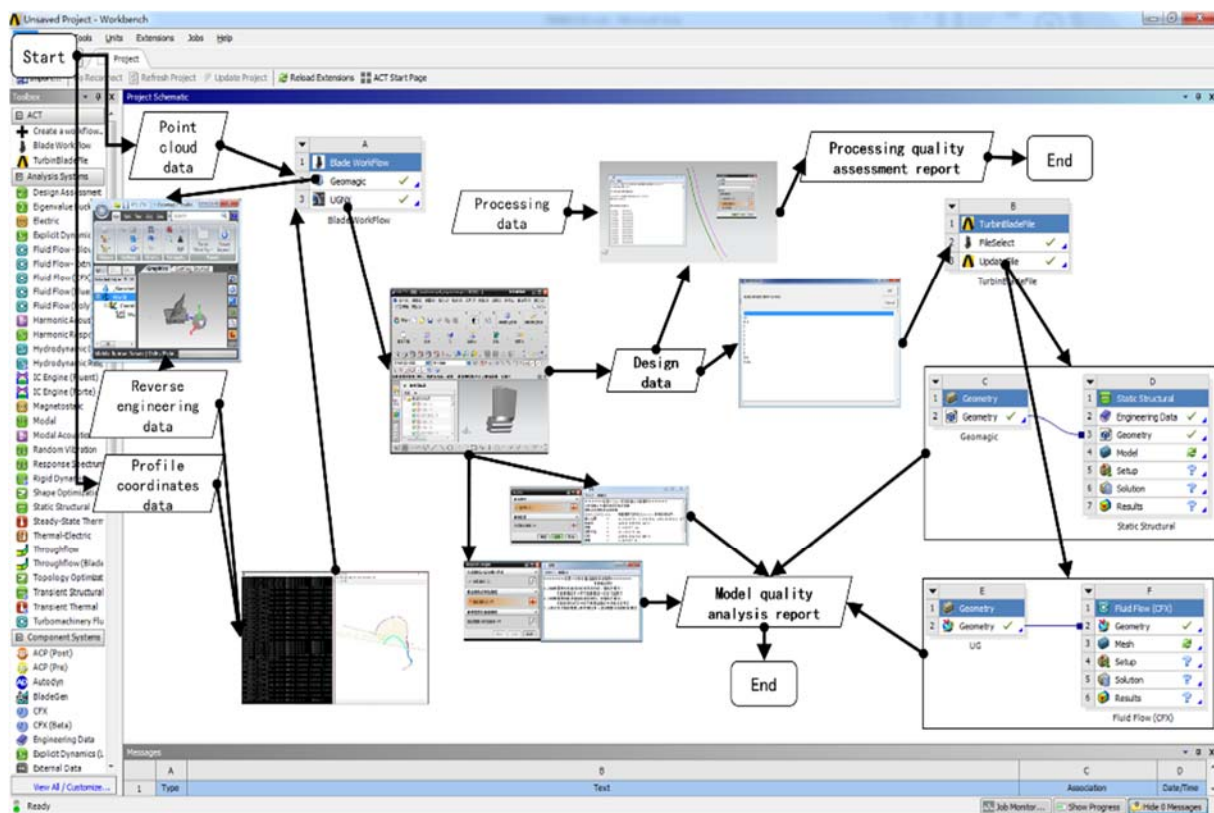


Figure 10. Turbine blade design and inspection software integration platform

5. Conclusion

The existing CAD software are usually for general design work, while in turbine blade design, special concerns will arise based on the relevant plant's existing habits and work requirements. So add-ins of some technical functions are heavily needed in real work. In this paper, functional modules aimed at guaranteeing the design models' uniforming quality as well as machining quality inspection are developed, these are based on general-purpose CAD software UGS, and can strengthen the primary functions of existing system. Also an integrated platform for the data sharing and workflow management is developed based on the newly developed add-ins. The work is highly focused on practical applications and oriented for real problem solution. Future work will explore the more close combination between different software used for blade design from more essential level, such as geometry representation, modelling history analysis and so on.

6. Acknowledgements

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7. References

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