Machining errors control method for near-net-shape jet engine blade CNC machining process

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Abstract: This study proposes a method based on on-machine measurement to control the machining error in the blade CNC machining process. Firstly, the mechanism of machining error formation of the near-net-shaped jet engine blade are analyzed, and the composition of the machining error source and its impact are qualitatively analyzed. Secondly, the adaptive CNC machining process are introduced. Thirdly, the influence of adaptive CNC machining process on the final machining errors is analyzed. The results show that the adaptive CNC machining process is of the excellent ability of machining errors control, and this method is effective in machining error control.

1. Introduction
At present, the shape of the blade is becoming more and more complex, the size of blade is larger, and the accuracy requirements are higher and higher with the continuous improvement of the bypass ratio, thrust-to-weight ratio and service life requirements of aero-engines [1]. The blade manufacturing with high performance and efficiency is a hot topic of current research. It is also one of the key processes for improving aero engine performance [2].

Near-net-shape jet engine blade is one of the key link in the performance improvement of the new jet engine due to the material removal link on the blade body surface. The main part of this kind of blade is to use the complex surface of the blade body as the positioning and clamping part to CNC machine the blade tenon root and tip. At present, the CNC machine of this kind blade tenon root and tip is a low melting point alloy casting process, which a certain ratio of low melting point alloy is used to package the blade body [3]. However, the blade position and size cannot be detected and adjusted, and there are problems such as long working procedures and environmental pollution during the CNC machining process.

In blade CNC machining process, the elastic and residual stress deformation will be easy to appear due to the complexity of the blade structure, cutting process and the difficulty to machine material, and the chatter and forced vibration will seriously affect the efficiency and quality of blade [4]. Therefore, the accuracy controlling of the blade contour has become one of the problems in blade CNC machining process.

2. Near net shape blade machining error
Table 1 is the specific machining error sources and error types, and the blade machining error that needs to be detected is also multi-target, and it can be seen that this is a typical multi-source and multi-process
error process.

### Table 1. Specific error sources and machining error types

| Source of error                  | Specific error source (x) | Error types (y)                  |
|----------------------------------|---------------------------|----------------------------------|
| Process system                   | Machine tool error        | Maximum contour                  |
|                                  | Error caused by tool path  | Blade chord length               |
|                                  | Machine tool thermal error| Chord inclination                |
|                                  | Machining program error    | Blade twist                      |
|                                  | Tool wear                  | Blade circular position          |
| CNC machining parameters         | Cutting depth              | Blade Rectangle Position          |
|                                  | Feed rate                  | Leading edge arc radius          |
|                                  | Spindle speed              | Leading edge arc center position |
| Fixture                          | Fixture positioning error  | Leading edge contour             |
|                                  | Fixture stiffness          | Trailing edge contour            |
|                                  | Clamping force             | Blade convex contour             |
|                                  | Fixture layout             | Blade concave contour            |
| Adaptive CNC machining process   | Online measurement error   | Maximum thickness                |
|                                  | Adaptive algorithm error    | Leading edge thickness           |
|                                  | CNC machining model        | Trailing edge thickness          |

3. **Adaptive CNC machining process**

Online- measurement and intelligent correction technology can realize automatic detection and CNC machining in a same machining tool by integrating a CMM into a five-axis machining center, which effectively reduces CNC machining errors and time consumption caused by offline measurement, and ensures processing continuity.

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![Fig. 1 Overall flowchart of adaptive CNC machining technology](image-url)
Figure 1 shows the overall flowchart of the adaptive CNC machining process. In order to ensure the CNC machining quality of the final blade, the Renishaw probe will be stored in the machine tool magazine, and the cutter and Renishaw probe can be switched arbitrarily by the cutter change system of machine tool. This method integrating the measuring head and the cutter in the same tool changing system of the machine tool will be one of the essential function of the adaptive CNC machining machine tool. At this time, the CNC machining coordinate system and online-measurement coordinate system of the machine tool will be reduced to the same coordinate system again, and the relative position between the measurement coordinate and the CNC machining coordinate will tend to 0.

Adaptive CNC machining process is able to make timely adjustments based on the current blade deformations, uneven blade margins of CNC machining and inaccurate clamping conditions to adapt to the current equipment or blade status and complete specific CNC machining process of blade. Specifically, the inaccurate clamping state of the blade can be quickly adapted to achieve accurate machining process under the condition of the inaccurate clamping of blade, through on-machine measurement and the corresponding algorithm. This technology is essentially on-machine measurement and intelligent correction technology, which can realize the integration of manufacturing and measurement. In the CNC machining process of blade production, only one clamping is required to perform real-time detection and intelligent correction of the entire production process, which will short the manufacturing cycle, reduce production cost, and improve product quality. On-machine measurement and intelligent correction technology can perform automatic real-time detection of products, and realize intelligent conversion of processing paths based on the offset of the measurement center and angle to ensure the accuracy of CNC processing position. The method of adaptive CNC machining process will be the following benefits:
1. Eliminating the secondary clamping error
2. Solving the problem that the clamping accuracy of the fixture is not high
3. Eliminating the clamping errors during clamping process
4. Solving the problem of blade deformation caused by previous cutting forces

On-machine measurement and intelligent correction technology can realize automatic detection and CNC machining in a same machining tool by integrating a CMM into a five-axis machining center, which effectively reduces CNC machining errors and time consumption caused by offline measurement, and ensures processing continuity.

4. Machining error control by adaptive CNC machining process
There are three stages of roughing, semi-finishing and finishing machining process the blade tenon root CNC machining process. The main purpose of roughing and semi-finishing process is to remove a large amount of allowance and improve machining efficiency, while the main purpose of finishing is to obtain excellent surface accuracy and meet the requirements of CNC machining accuracy. In the processing links of the tenon root, the only available positioning surface is the blade contour. However, this contour has a contour error of 0.008-0.05mm with inconsistent initial accuracy. The adaptive CNC machining technology can reasonably reduce the benchmark error caused by the initial positioning accuracy. In order to verify the reliability of the proposed adaptive CNC machining process method, the blade contour is measured by on-machine measurement.
Figure 2 shows the measurement process of the blade on the machine. 24 points on the blade body are selected as the measurement points for measurement. And judge the change of blade single-point deviation value before and after adaptive CNC machining process.

Figure 3 The blade single-point deviation value of before the adaptive CNC machining process.

It can be seen that before the adaptive CNC machining process, the single-point deviation value of some measurement points on the leaf pot and the back surface of the blade is greater than 0 mm, and some are less than 0 mm, which indicates that the blade is not in an ideal state.

Figure 4 The blade single-point deviation value of after the adaptive CNC machining process.

Figure 4 shows the single-point deviation value of the blade body measurement points after adaptive processing. It can be seen that the single-point deviation values of all the measurement points on the
blade surface are all positive at this time, which indicates that the blade blanks are evenly distributed in on both sides of the theoretical model of the blade, the blade is in an ideal position at this time. The adaptive CNC machining process plays a role in adjusting the blade surface curvature, so that the blade surface is closer to the blade theoretical surface. The adaptive CNC machining process can reduce machining errors caused by positioning benchmark errors based on the on-machine measurement and the method of machining model reconstruction, which is a method of machining error elimination.

5. Conclusion
The adaptive CNC machining process method proposed in this paper can reduce the machining error reasonably, and play a good role in the reduction of multi-source and multi-process machining error.

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