Research on Machining Fixture of Near-Net-Shaped Jet Engine Blade

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Abstract. This paper focus on the design and verification of the machining fixture on the background of the adaptive processing technology. Firstly, the positioning and clamping scheme of near-net-shaped jet engine blades are introduced and analyzed, especially the new materials (Polyetheretherketone (PEEK-GF30)) and new structure are applied to fixture, and corresponding fixture is designed, manufactured and applied to engineering. Secondly, the relationship between the blade clamping deformation and clamping force is analyzed by finite element method (FEA). Thirdly, blade cutting deformation is analyzed by cutting experiment. The results show that this new material and structure fixture combined with CNC adaptive processing technology can achieve the precision machining of near-net-shaped jet engine blades Tenon root.

1. Introduction
Blades are the key components of the contemporary aero-engine, and structure design and machining quality of the blades play a vital role in the engine performance [1, 2]. The new generation of aero-engine blade is usually manufactured by precision forging process. Quality of the blade surface by precision forging is guaranteed by the forging die, which doesn’t need the secondary processing after forming. However, leading edge and tailing edge can not be formed by precision forging [3]. Because of forging deformation, clamping deformation and so on, leading edge and tailing edge of the blades can not be manufactured according to the theoretical model, and the CNC machining procedures can not be directly shared in the mass production. In order to solve the problems of connection department between the actual surface of the blade and leading edge and tailing edge of the theoretical model, forming of leading edge and tailing edge of the blades, and NC machining program translation in mass production of precision forging blades and so on [4].

A new generation of aero-engine blades uses precision forging to make blanks. Precision forging is a new process with little cutting-free machining developed on the basis of ordinary die forging [5]. The precision forging process ensures the continuity of the metal inside the blade, increases the strength and load carrying capacity of the blade, and improves the performance and life of the blade. The quality of the blade surface of precision forging is guaranteed by the forging die, and the forming precision is high. The shape of the blade body after forming does not need secondary processing [6].
However, the variable radius of the blade is not smooth and the forging edge cannot be formed by precision forging. Must be reprocessed [7].

![Diagram of adaptive NC machining technology](image)

**Figure 1.** The flow chart of adaptive NC machining technology

Adaptive CNC machining technology is integration of digital detection, digital detection model reconstruction, and NC machining. And the flow chart is shown in Figure 1. The adaptive NC machining technology [8, 9] is based on the design model of the parts to be machined and the corresponding machining program. According to the measured results of the machining area, the orientation change and shape deviation of the part model are obtained, and the actual machining is adaptively generated on the basis of the nominal machining program [10, 11]. The processing code of the area and guarantees a smooth transition to the results of the previous process. This technology is a system engineering technology, which not only covers CNC machining programming technology and surface modeling technology in CAD/CAM [12], but also involves several key technologies such as digital detection, reverse engineering, workpiece clamping positioning, etc. An important part of technological research and development [13, 14].

2. Description of positioning and clamping scheme

In structure, there are nine positioning (or assistant positioning) heads to contact with the body of blade, which is a typical multi-point positioning scheme. Specifically, there are 3 auxiliary positioning points based on the original 6-point positioning of the fixture (see Figure 2).

![Positioning and clamping scheme of blade](image)

**Figure 2.** Positioning and clamping scheme of blade

In the fixture, the main structural components are made of steel, and the clamping heads and positioning heads are made of Polyetheretherketone (PEEK-GF30) material, and the main material of blade is Ti-6Al-4V, and the material properties of blade and fixture components are shown in Table 1.
### Table 1 Material properties of blade and fixture components

| Material   | Young's modulus | Poisson ratio | Density    |
|------------|-----------------|---------------|------------|
| Ti-6Al-4V  | 110 GPa         | 0.36          | 4.40 kg/m³ |
| PEEK-GF30  | 7 GPa           | 0.38          | 1.51 kg/m³ |
| STEEL      | 220 GPa         | 0.3           | 7.80 kg/m³ |

3. Analysis of clamping force and deformation

Figure 3 is influence curve of single clamping force on deformation, and the other clamping forces are 500N in this case. It can be seen from Figure 3 (a) that deformation maximum gradually decreases with the increase of F1. Until F1 is more than 800N, deformation maximum will increase with the increase of F1. It can be seen from Figure 3 (b) that deformation maximum gradually decreases with the increase of F2. It can be seen from Figure 3 (c) that deformation maximum gradually decreases with the increase of F3. Until F3 is more than 500N, deformation maximum will increase with the increase of F3. It can be seen from Figure 3 (d) that deformation maximum gradually increases with the increase of F4. When F4 is less than 500N, the increase rate is relatively flat, and when the force is greater than 500N, the increase rate is obvious.

Experiment is arranged in order to verify the correctness of finite element calculation results. In this experiment, the clamping force is measured by film force sensor, and maximum deformation is obtained by electrical vortex sensor, and corresponding curves between the maximum deformation and clamping force is shown in Figure 4. It can be seen from Figure 4 that the finite element calculation results are basically consistent with the experimental test results when the clamping force is greater than 400N, and the deviation between the finite element calculation result and the experimental test

![Figure 3](image-url)
result is relatively large when the clamping force is less than 400N. This is because the contact area is changing with the changing of clamping force.

Blade is directly contacted by the positioning element. Firstly, the blade profile error is large because of blade complex surface characteristic and precision forging processing. Secondly, in order to make the clamping and positioning elements effectively contact to blade surface, positioning and clamping device must be fitted blade surface shape. However, the positioning and clamping elements and blade surface contact surface area are not complete because of the machining process error of actual clamping element.

Therefore, the contact process is not in accordance with the ideal surface contact because of the positioning elements, clamping elements and blade machining errors. Experiment is arranged in order to identify the change of contact areas. A layer of oil was applied to the surface of the blade to observe the change of oil coating area after clamping force in this experiment. It can be seen from Figure 4, the contact area is as an "8" word area when clamping force is 500N, and the contact area is a "0" word area when the clamping force is 1000N. So it can be concluded that the positioning and clamping elements and blade surface contact surface area gradually increases with the increase of clamping force, contact area is starting point contact, after the "8" word area contact, to the final "0" word area contact.

![Figure 4. Results comparison of calculation and experiment](image)

Therefore, it is necessary to reset the contact area according to the different contact area, which leads to the decrease of the calculation precision of finite element. The results of finite element calculation are acceptable considering the influence of contact area, which also indicates that the finite element model established above is reliable.

![Figure 5. Cutting process](image)
4. Analysis of cutting experiment and cutting deformation
Cutting experiment, displacement response measurement and the application of fixture is carried out, and the test setup is shown in Figure 5. The cutting process parameters are shown in Table 2.

| Machining parameters | Rotation speed | Feed rate       | Cutting depth |
|----------------------|----------------|-----------------|---------------|
| Roughing milling     | 800 rpm        | 0.3mm/min       | 5mm           |
| Finishing milling    | 1200 rpm       | 0.2mm per tooth | 0.2mm         |

As shown in Figure 6, it is the change of the blade cutting force RMS of the roughing and finishing under the corresponding process parameters. It can be seen that the roughing cutting force is much larger than the finishing cutting force, because the roughing mainly improves the blade cutting efficiency. Cutting efficiency is dominant, so a large amount of cutting material removal is required, resulting in a large depth of cut. Therefore, the cutting force is large.

As shown in Figure 7, it is the change of the cutting deformation of the roughing and finishing blades under the corresponding process parameters. It can be seen that the cutting deformation of the roughing blades is much larger than the finishing cutting deformation, because the roughing cutting force is much larger than the finished cutting force.

However, these cutting deformations are acceptable for comparison with machining accuracy requirements, and the machining deformation is small. This also shows that the proposed fixture meets the process requirements and can be used in the manufacture of blades in the context of adaptive CNC machining technology.
5. Conclusion
In this work, machining fixture in adaptive CNC machining process of near-net-shaped thin-walled blade were investigated by theoretical analysis, FEA and engineering experiment test. The results can be summarized as follows:
1) The results of FEA are acceptable considering the influence of contact area, which also indicates that the established FEM is reliable.
2) The proposed fixture and process can realize high-precision blade manufacturing, and can be used in the industrial production of blades

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