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Research of Machining Vibration Restraint Method for Compressor Blade

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Abstract

Machining vibration is one of the most important reasons that influences the tool life, machining efficiency and the final surface quality, the performance and the reliability of aero-engine is affected directly by compressor blades. To restrain machining vibration of compressor blade in multi-axis machining, the mechanism of vibration and milling force during machining thin-walled blades is analyzed. A model of machining vibration and a vibration differential equation are established. Response function of blade reflects that the amplitude is influenced by clamping stiffness of blade, the natural frequency and damping of blade-fixture system. The paper presents a method of tension clamping to increase stiffness and natural frequency of system. Experiments show that the method can reduce clamping deformation, increase blade stiffness and natural frequency of blade-fixture system. It can reduce machining vibration eventually.

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Keywords: Compressor Blade, Vibration, Stiffness, Natural Frequency, Tension Clamping;

1. Instruction

Aero-engine is known as the heart of aircraft, the operating temperature, rotating speed and reliability are demanding increasingly with the development of technology. Compressor blade is one of the most important components of aero-engine. Higher performance compressor blade is needed to satisfy larger alternating and impact load and higher operating temperature. Compressor blade is mainly machined with titanium alloy or super alloy in multi-axis machining center. Weak rigidity of the blade and poor machinability of the blade material lead to machining vibration generated easily during machining. Machining efficiency is low, surface quality is poor and tool wears fast due to vibration. The final accuracy of compressor blade is relying on manual polishing.

One of the important factors that leads to product deformation is clamping force [1]. G. H. Qin et al. [2] analyzed the mechanism of clamping deformation of thin-walled workpiece and presented a general methodology to optimal the magnitude, placement and clamping sequence of a clamping scheme. H. Y. Dong et al. [3] presented a method to simulate the clamping operation for thin-walled frame parts using finite element models. Lu Dong et al. [4] revealed the influence of friction force and chip removal on the clamping force using finite element numerical calculation model. G. H. Qin et al. [5] using the nonlinear mapping of neural network, established a prediction model of clamping deformation according to the training samples and then presented an optimal model of multi-fixturing layout with the objective of minimizing the fixturing deformation. Nevertheless, these studies were mainly aimed at frame parts and not suitable for blade.

L. Y. Zheng et al. [6] presented a method to improve machining accuracy of thin-walled parts through preventive simulation and numerical control process improvement. T. Y. Wang et al. [7] established a vibration model of thin-walled workpiece in the end milling through milling experiment and validated the accuracy of the model in actual milling. Y. Wang et al. [8] proposed a method of finite element analysis on a system of a fixture and turbine blades by considering the complex contact geometry and complicated contact status of fixture-component pairs using surface-to-surface contact elements and verified the finite element analysis prediction of the elastic deformation of fixture and turbine blades system. M. Luo et al. [9] presented a tension clamping method of blade and

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analyzed the variation of frequency and stiffness with cutting steps, but they ignored the influence of tension force.

The article analyzes the machining vibration of blade and presents a clamping method to enhance stiffness of blade and change the natural frequency of blade-fixture system. The change rules of stiffness and frequency have been wildly studied through experiments. Experiments show that stiffness of blade and the frequency of blade-fixture system are increased effectively, and the damping of system is changed with the tension force.

2. blade model in milling

The shape of compressor blades is free-form surface. It is mainly machined with overall material in milt-axis machining center. The blade root is clamped to A axis of machining center and compressed with tailstock during machining at present. As shown in Fig. 1, the blade can simplify to a simply supported beam model. The frequency of blade can be expressed as below.

$$\omega=\sqrt{\frac{k}{m}} \tag{1}$$

Where k is stiffness, m is mass.

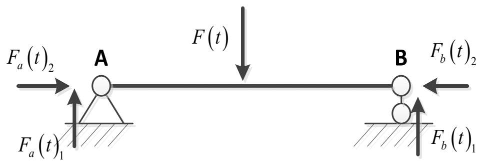

Fig. 1 Simplified model of blade-fixture

As shown in Fig. 1, cutting force can be simplified as a dynamic load $F(t)$. Blade-fixture system is doing forced vibration under the action of cutting force. The clamping force is simplified to two constraining force $F_a(t)_1$ and $F_a(t)_2$, the compression force is simplified to $F_b(t)_1$ and $F_b(t)_2$.

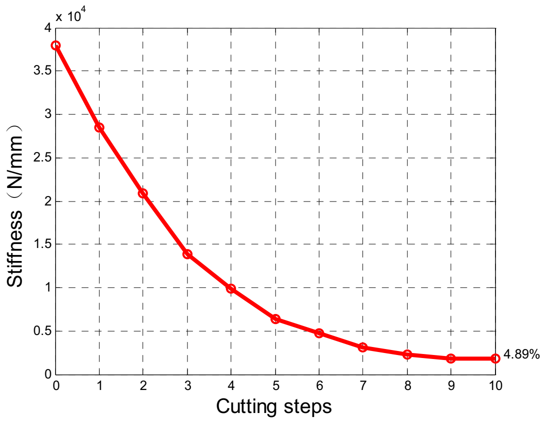

Fig. 2 Variation of stiffness with cutting steps

As shown in Fig. 2, the workblank of blade has large stiffness, but it decreases sharply with the 90% material removed during machining. Therefore, the blade became a typical weak rigidity part and deforms easily during semi-finish and finish machining.

3. Vibration analysis

3.1. Milling force analysis

Ball-end milling cutter and tiny feed rate are usually used in semi-finish and finish machining of blade to get better surface quality. As shown in Fig. 3, the dynamic milling force graph is acquired in the semi-finishing of blade through experiment.

We can see from the dynamic milling force graph that semi-finishing machining is an intermittent cutting process. Milling force can be equivalent to a periodical impact load. The frequency of the load can be expressed as $\omega = i \cdot m$, where i is the teeth number of the cutter, m is spindle speed. The instruments and process parameters of experiment are show in the table 1. Namely, the machining vibration of thin-walled workpiece is originated form cutting force.

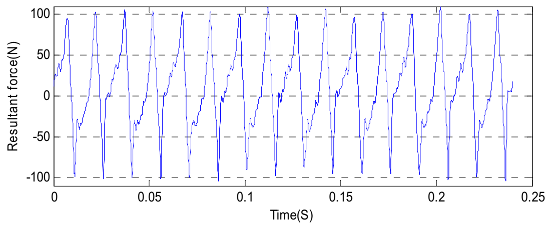

Fig. 3 Dynamic milling force of blade in semi-finishing process

Table 1 instruments and process parameters of experiment

data acquisition device	Piezoelectric dynamometer	Cutting Depths (mm)
UEI DNR-12-1G	Kistlter 9255B	0.5
Cutter	Spindle Speed (r/min)	Feed Rate (mm/min)
$\phi 10\times 32\times 92-Q4$ ball-end carbide cutter	2000	600

3.2. Machining vibration analysis of blade

The machining vibration of blade is different from the vibration of conventional workpiece, except for chatter, deformation of the workpiece is another important reason that causes machining vibration. The machining process of blade is analyzed using the milling vibration theory, a vibration model of blade between semi-finishing and finishing period is obtained and shows in.

As shown in Fig. 4, $F_b(t)_2$ is axial component of clamping force, it can aggravate blade deformation and increase vibration during machining. The surface quality of blade decreases seriously because of vibration, the manual polish thickness and process-cycle increase simultaneously.