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Control of Helical Blade Machining in Whirling

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Abstract
Machinings of helical blades have recently been increased with manufacturings of aircrafts and energy facilities. The helical blades have generally machined in ball end millings on the multi-axis machining centers. Because high machining rates and low machining costs have been required for the blade machinings, more effective processes are required to improve the machining performances. This study applies whirling process to the blade machinings. The whirling process is performed in the workpiece and the tool rotations with eccentricity of their centers. A mechanistic model is presented to control the blade shape in the whirling process. Then, the cutting tests were conducted with a turning tool on a turning center. In the presented cutting, the helix angle and the helical orientation are controlled by the feed rate and the ratio of the tool spindle speed to the workpiece one, respectively. The machining errors and the surface finishes were also measured in whirling of the blades. The machining error at the free end of blade is larger than that of the clamping side of blade. The surface finish at the clamping side is worse than that of the free end of blade, which is induced by the vibration of the tool.

Keywords: Cutting, Whirling, Helical blade, Titanium alloy, Machining accuracy, Surface finish

1 Introduction

Blade machining has recently required for the hydraulic or pneumatic parts in aerospace and energy industries (Harik *et al.*, 2012). The helical blades have also increased to be embedded in human bodies as the medical implants (Yang, 2005). The blades are shaped helically in the blade axes and are usually manufactured on 5-axis machining centers (Roth *et al.*, 2001). Furthermore, the blades are made of difficult-cut-materials such as titanium alloy (Tetsui *et al.*, 2002). The tool wear and the chatter vibration, therefore, should be controlled to assure the machining accuracy and the surface finish (Gong and Wang, 2011).

Generally, the blades have been machined in ball end millings on multi-axis machining centers. It takes a long time to complete machining. The numerical data are also prepared for control of the blade

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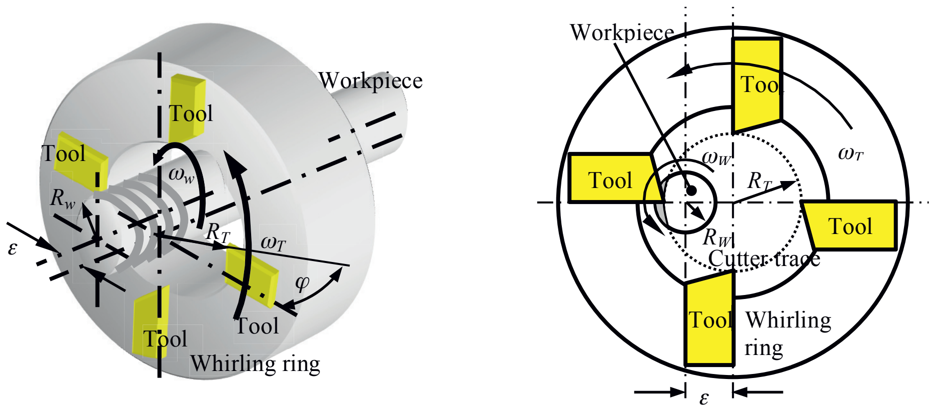

(a) Thread whirling (b) Cutter trace

Figure 1: Whirling

shape in the milling. Therefore, more effective processes are required to improve the machining performances in the blade machinings. This study presents a novel approach to machine the helical blades with a turning tool on a turning center, in which the whirling process is applied to control the blade shapes with only the cutting parameters. Therefore, the presented approach does not require the complicated numerical data to form the curved shape.

Whirling has been applied to screw manufacturing in many mechanical industries since Burgsmuller company in Germany developed the machining method. Worm and ball screws for motion controls and implant parts (Yokoyama *et al.*, 2002), which are made of hard materials such as stainless steel, have been machined in whirling. Having many advantages in terms of the tool wear and the chip control, the whirling process has been widely applied in the bearing and the medical industries. Mohan and Shunmugam presented a mathematical model to control cutting processes and determined the tool profile in whirling (Mohan and Shunmugam, 2007). Lee *et al.* made a model of the undeformed chip shape to estimate the cutting force with getting the maximum chip thickness and the tool-work contact length. They divided the undeformed chip shape into the material removed by the front cutting edge and that of the side cutting edge. Then, the cutting force was estimated in FE analysis (Lee *at al.*, 2008). Son *et al.* measured the cutting force components with a non-contact rotating tool dynamometer and compared the simulated cutting forces in FE analysis tools, DEFORM and ADAMS (Son *et al.*, 2010). Although the whirling process has been performed in the manufacturing plants so far, the process has applied to only the screw machining.

This study applies the whirling process to the blade machining, as an advanced application of whirling. The paper describes the outline of the whirling process with the advantages in the machining. Then, a mechanistic model is presented to control the machining shape for the cutting parameters. The cutting parameters are determined to machine the helical blades in the simulation. The cutting tests were conducted to control the blade shapes with the cutting parameters and measure the machining accuracies and the surface finishes in the helical blade machinings. The machining shapes are also compared to the simulation based on the machining model in discussion of machining accuracies.

2 Whirling Process

The whirling process is generally performed to machine the screws in combination of the tool and the workpiece rotations, as shown in Fig. 1. The cutting tools are clamped on the whirling ring at the