A Micro Feeding Tool Holder with Bellows-type Hydraulic Displacement Amplification Mechanism

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Abstract

To improve the feeding resolution of an existing desktop ultraprecision machine, a micro feeding tool holder with a displacement magnification mechanism was developed. The feeding stroke of the tool holder actuated by stacked piezoelectric (PZT) actuators could be amplified through a bellows-type hydraulic device with two different cross-sectional areas. According to experimental results, a displacement amplification ratio of 4.4 and a feeding resolution of less than 10 nm were obtained. In order to perform cutting experiment, a position control system of the tool holder configured by FPGA (Field Programmable Gate Array) module was implemented. Through the examination of flat cutting for an oxygen-free copper (OFC) workpiece, a mirror surface with roughness of Ra 16 nm was obtained. The tool holder that features high-precision and large stroke has been demonstrated.

1 Introduction

Recently, due to rapid development of optoelectronic industry, various demands for high-precision and micro complex optical components increasingly appear. To support the manufactures of these components, a machine tool equipped with a high performance tool holder is essential. In this paper, a micro feeding tool holder with bellows-type hydraulic displacement magnification is studied. The development of tool holder is aimed at increasing the feeding resolution of an existing machine tool and providing tool servo function for future asymmetric-axis machining.

In previous study [1], a new structure of directly connecting the PZT actuators to the bellows-type hydraulic displacement magnification was proposed to improve the actuating performance of a current tool holder [2], in which the displacement transmission of PZT actuator was based on physical contact. In this paper, an

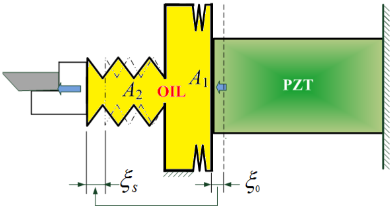

Figure 1: Schematic diagram of proposed tool holder.

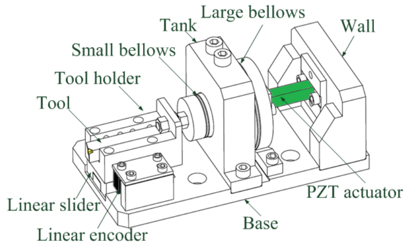

Figure 2: Detail design of the micro feeding tool holder.

actuating system of the tool holder configured by FPGA module is implemented, and the cutting performance based on the configured control system is reported.

2 Operation principle and detail design

The operation principle of the tool holder with displacement amplification mechanism is schematically shown in Fig. 1. The tool holder includes a closed chamber with two different cross-sectional diameters, two bellows separately mounting on both sides of the chamber, hydraulic oil used as the transmission media filled fully in the chamber, and a PZT actuator.

As shown in Fig.1, when applying a driving voltage to the PZT actuator, a steady displacement ξ_0 is induced and smoothly transmitted to the chamber wall through larger bellows. As a result, the hydraulic oil is pressurized and thus causing the smaller bellows to expand. This results in a magnified displacement of ξ_s based on the area ratio of two different cross-sectional diameters of the chamber as follows:

$$A_1 \times \xi_0 = A_2 \times \xi_s \quad (1)$$

where A_1 and A_2 are effective cross-sectional areas of the chamber on PZT actuator side and tool holder side, respectively.

According to the proposed mechanism, the tool holder is designed as shown in Fig. 2. The stacked PZT actuators are with an electromechanical coupling of 17.7/100 μm/V. Two bellows are with different outer diameters of ϕ52.5 mm and ϕ24.4 mm, respectively, and the displacement magnification ratio is calculated as 4.6. A tool holder is connected to the chamber wall, and is guided by a linear slider (THK VRT 2035A). A linear optical encoder (Renishaw Tonic Ti4000) with a resolution of 5 nm is mounted beside the tool holder for motion detection.

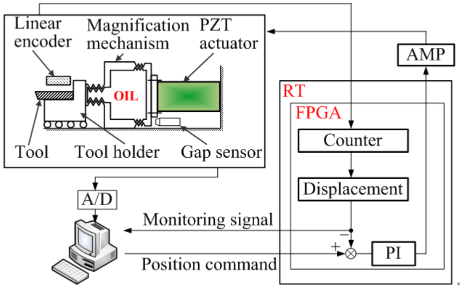

Figure 3: Real-time (RT) control system.

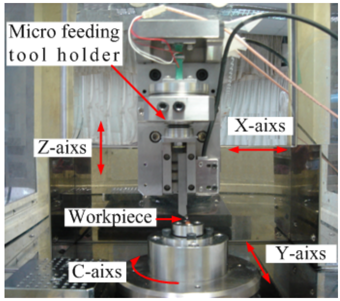

Figure 4: Experimental setup.

3 Experimental setup

The experimental setup for performing experiments is shown in Fig. 3. A real-time (RT) control system consisting of PI controller is configured by FPGA. To perform flat cutting, a position command is given through the computer to the RT control system. The voltage command determined by the control system is fed into a power amplifier (nF: HSA-4014) for the actuations of PZT actuators. A linear encoder and a gap sensor (ADE5502) are used to simultaneously detect the motions of tool holder and PZT actuators, respectively. The experimental setup for performing flat cutting is shown in Fig. 4, where the micro feeding tool holder is mounted vertically.

4 Experimental results

4.1 Stepwise actuations

Fig. 5 shows the experimental results of continuous stepwise actuations for both forward and backward actuations of the tool holder. The step commands were given

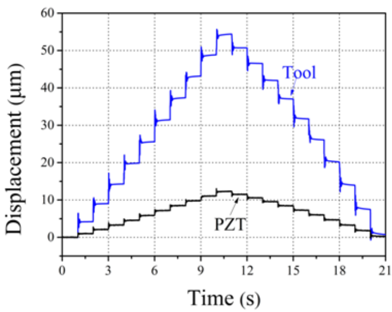

Figure 5: Forward and backward step actuations.

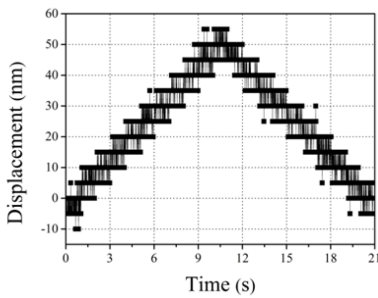

Figure 6: Control performance due to finest step command of 5 nm.

by 1 Hz with a constant changing amplitude of 10 V per step. The displacement caused by each step actuation is about 5.4 μm. Comparing the displacement of tool with the displacement of PZT actuator, the magnification ratio is derived as 4.4.

Fig. 6 shows the actuating performance obtained by the finest step command of 5 nm, which is the resolution of linear encoder. Although the step motions are with fluctuation, the trends of forward and backward motions are clearly visible.

4.2 Flat cutting

Experiment of flat cutting for an OFC workpiece was performed, with mirror surface shown in Fig.7. The machining parameters were the feeding speed along X–axis being 30 mm/min, the revolution of main spindle being 300 rpm, and depth of cut being 10 μm. The surface roughness measured with Alpha-Step IQ was obtained as Ra 16 nm.

Figure 7: Mirror surface obtained by flat cutting.

5 Conclusion

In this paper, a micro feeding tool holder with a hydraulic bellows-type displacement amplification mechanism was studied. The displacement amplification ratio was obtained as 4.40, and actuating performance configured by PI controller could be obtained as precision as under 10 nm. Through the experiment of flat cutting, a mirror surface with roughness of Ra 16 nm was obtained.

Acknowledgements:

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[1] Y.-T. Liu, L.-L. Chang, "Study of a Micro Feeding Tool Holder with Bellows-type Displacement Amplification Mechanism", *The First IFToMM Asian Conf. on Mechanism and Machine Science*, Oct. 21-25, 2010, Taipei, Taiwan, 250123.

[2] Y. Morimoto, et. al., "Development of Cutting Device with Enlargement Mechanism of Displacement," *J. of Advanced Mechanical Design, Systems and Manufacturing*, Vol.2, No.4, pp.474-481, 2008.