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A fast tool servo feeding mechanism of a swing feed ultra precision diamond turning machine

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Abstract
A fast tool servo feed mechanism is designed to facilitate the machining of precision large aspheric surface components with big asphericity and profile precision with sub-micron accuracy on a swing feed ultra-precision diamond turning machine. The swing feed ultra-precision diamond turning machine incorporates a swing arm that allows the cutting tool to rotate around the axis of hydraulic motor which is not parallel to the axis of spindle which workpiece is installed one to enable the machining of spherical surface, and accurately machining of aspheric surface parts often requires that the cutting tool can move precisely along the spherical surface normal. The fast tool servo realizes the tool position using flexures with high stiffness that is designed using finite element analyses. The flexures are driven by piezo actuators, which provides a position accuracy of 55 nm.

Keywords: Ultra-precision diamond turning; Flexure hinge; Fast tool servo; Swing feed

1. Introduction

Ultra precision diamond cutting has been applied in producing of precision part with the development of ultra precision machine tool. During cutting, fast too servo (FTS) and slow slide servo (SSS) feeding system are utilized to generate flat surface, spherical surface, aspheric surface, microstructures and freeform surface for optics parts [1-2].

Over the past decades, considerable researches have been conducted on FTS or SSS [3-5]. Previously designs mainly were suitable for the principle of processing of ultra precision diamond turning machines based on T-type structure, for example, the ultra-precision 2-axis CNC diamond turning lathe of Moore Nanotechnology Systems, LLC [6]. Ideally, the section of chips is supposed to be constant, and the cutting force is constant during cutting with T-type structure lathe.

In this paper, the manufacturing of parts is based on the swing feed of the ultra-precision diamond turning machine During cutting, the section of chips is not constant, and changing at every second, then the cutting force is not constant too. To getting a good surface, a fast tool servo feeding mechanism with high stiffness and high positioning accuracy to realize high precision feeding and inexpensive is developed in this paper.

2. Design and Modal of flexure hinge amplifying structure

To get a travel of 120 μm and decrease the volume of feed mechanism, this feeding mechanism is based on amplifying structure and piezoelectric actuator. The section and mechanical modal of feed mechanism based on flexure hinge amplifying structure are illustrated in Fig.1.

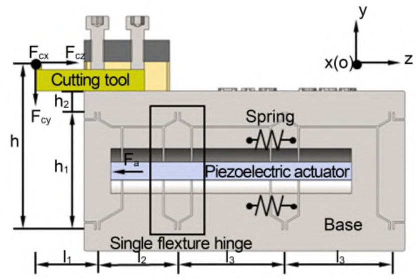

Figure 1. Mechanical modal of flexure hinge based on amplifying structure

F_c is the cutting force, F_{cx}, F_{cy}, F_{cz} are component forces of cutting force F_c in *X* direction, *Y* direction and *Z* direction separately, which are as follows:

$$F_c = \sqrt{F_{cx}^2 + F_{cy}^2 + F_{cz}^2} \tag{1}$$

$$F_{cx} = \frac{2F_{fx}(l_2+3l_3)}{2l_1+l_2+2l_3} \tag{2}$$

$$F_{cy} = \frac{2F_{fy}(l_2+3l_3)}{2l_1+l_2+2l_3} \tag{3}$$

$$F_{cz} = \frac{(F_a-F_s-8F_{fz})\cdot h_1}{2h} \tag{4}$$

where F_a is the output force of piezoelectric actuator, F_s is the output force of spring.

$$F_s = K_s \cdot \delta_s \tag{5}$$

where K_s is the stiffness of spring, d_s is the equivalent deformed length of spring.

The force of a single flexure hinge can be simplified as below:

$$\mathrm{F_f} = \mathrm{K_f} \cdot \delta_f \tag{6}$$

Where F_f is the equivalent force of a single flexture hinge. K_f is the equivalent stiffness of a single flexure hinge. d_f is the equivalent deformation of a single flexure hinge.

Supposing that there are three forces of 10 N at the cutting point in X, Y and Z directions separately. Form the result of computation in Fig.2, the stiffness of the setup is more than 20 N/μm, which is enough for the cutting force that is less than 2 N in fact.

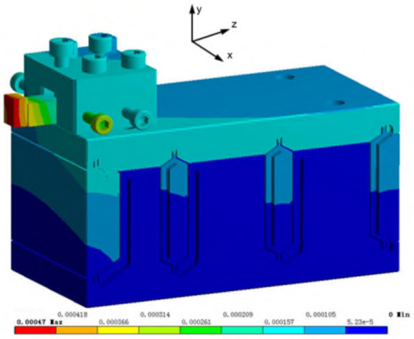

Figure 2. Finite element analys of fast tool servo mechanism

3. Position accuracy

To determine the position accuracy and resolution of feed motion of fast tool servo feed mechanism in the direction of feed, and some experiments have been conducted, the capacitive sensor and NI data acquisition card has been used to measuring the position accuracy and resolution of fast tool servo feed mechanism. Fig.3 contains a plot of the data measured by a capacitance probes when the fast tool servo feed mechanism was drived 90 times back and forth of 120 μm travel, and computed according to ISO 230-2-2014 [7]. After several times back and forth, the position accuracy will reach a level of 55 nm.

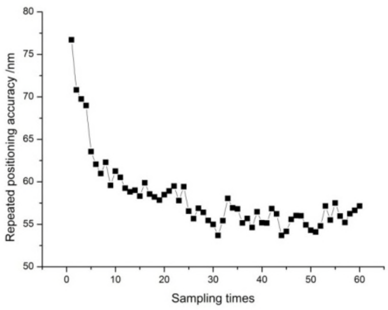

Figure 3. Measurement of repeated positioning accuracy

4. Conclusion

This paper presents a three-dimensional modal and modal of mechanical analysis of fast tool servo feeding mechanism. From the result of finite element analysis and position accuracy test with capacitive sensor, the performances can be achieved, the stiffness of the setup is more than 20 N/μm, and position accuracy is 55 nm.

References

[1] Senthil Kumar, A., M. R. Aravind Raghavendra, et al. (2014). Fast and Fine Tool Servo for Ultra-precision Machining. Comprehensive Materials Processing. Elsevier **10**: 61-88.

[2] Lu, H., S.-c. Choi, et al. (2012). "Microstructure of fast tool servo machining on copper alloy." Transactions of Nonferrous Metals Society of China 22: s820-s824.

[3] Ma, H., J. Tian, et al. (2013). "Development of a fast tool servo in noncircular turning and its control." Mechanical Systems and Signal Processing 41(1-2): 705-713.

[4] Rakuff, S. and J. F. Cuttino (2009). "Design and testing of a long-range, precision fast tool servo system for diamond turning." Precision Engineering 33(1): 18-25.

[5] Liu Q, Zhou X, Xu P, Zou Q, Lin C (2011) A flexure-based long-stroke fast tool servo for diamond turning. The International Journal of Advanced Manufacturing Technology 59(9-12): 859-867.

[6] Moore Nanotechnology Systems, LLC. http://www.nanotechsys.com/machines/nanotech-250uplv2-ultra-precision-lathe/

[7] ISO 230-2 (2014) Test code for machine tools-Part 2: Determination of accuracy and repeatability of positioning of numerically controlled axes. International Organization for Standardization, Switzerland