http://ansinet.com/itj

ITJ

ISSN 1812-5638

INFORMATION TECHNOLOGY JOURNAL

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Information Technology Journal 12 (15): 3237-3240, 2013
ISSN 1812-5638 / DOI: 10.3923/itj.2013.3237.3240

The Development of 4-axis Ultra-precision Lathe

Yang Jinrong, Li Chaojiang, Gao Xing and Li Yong
State Key Laboratory of Tribology, Tsinghua University, Beijing, 100084, China

Abstract: A 4-axis ultra-precision lathe with a rotary B axis is introduced, including its overall structure features and performance parameters and also its air motorized spindle, air linear guide and rotary worktable are described. Open PA NC system is used and ultra-precision grating is employed as full closed feedback device. The rotary accuracy of spindle is 0.05 μm, the straightness error of guide is 0.15 μm/200 m and the displacement resolution is 2 nm and the rotary accuracy of B axis is 3″. In order to verify comprehensive performance of the lathe, large flat surface, semi-sphere, complex curved surface and parabolic are machined. The result shows that by using the lathe, mirror surface can be obtained.

Keywords: Ultra-precision lathe, mirror surface machining, complex curved surface machining

INTRODUCTION

The development of ultra-precision machining technology directly influences the development of a nation's sophisticated technology. Thus, western countries and Japan have spent a huge amount of research fund on it and the key technology is kept secret (Yuan, 2006). Now the definition of ultra-Precision has not been in complete agreement which means the division of machining process is changed with the development of technology level, for instance, precision machining defined in the past is probably seen as traditional machining nowadays (Li and Dai, 2003). The famous Taniguchi (1983) curve can describe the development of machining precision in the past sixty years: now the ultra-precision machining accuracy reaches a nanometer level. At present, a view of machining accuracy generally accepted is that for precision machining, the geometrical accuracy is between 0.1~1 μm and the surface roughness (Ra) is between 0.025~0.1 μm and that of ultra-precision machining are respectively less than 0.1 μm and less than 0.025 μm. Ultra-precision machine tools play a critical role in machining mirror surface with sub-micron level geometrical precision and nanometer level surface roughness.

The research and manufacturing of ultra-precision machine tools began in 1960s, when the USA needed a kind of large metal reflection mirror for laser nuclear fusion device and infrared device (Li and Zhu, 2000). By using single point diamond cutting tool, aluminium alloy and oxygen-free copper with mirror surface were successfully turned which boosted the development of ultra-precision machine tools. In 1980s, the LLNL laboratory in the USA developed a series of ultra-precision machine tools for experimental research, including a large optical diamond lathe-LODTM. A work piece with a diameter of 2.1 m and a weight of 4.5 ton can be machined by this lathe, straightness error of the guides and motion resolution of which are less than 0.025μm and 0.005μm, respectively.

Later on, Moore Corporation, Pneumo Corporation of the USA and Phillips Corporation in Holland launched small and medium size ultra-precision lathes in succession (Li *et al*., 2010; Lee *et al*., 2005). These NC aspheric lathes were equipped with diamond cutting tool, by which geometrical precision with 0.3~0.5 μm and surface roughness (Ra) with 10 nm can be obtained.

In recent years, certain research institutions as well as universities and colleges in China have done a great deal of research work on ultra-precision machine tools and have made some progress and achievements, such as Beijing Machine Tool Research Institute, Harbin Institute of Technology, Changchun Institute of Optics, Fine Mechanics and Physics, Chinese Academy of Sciences and National university of Defense Technology (Dong, 2010; Li *et al*., 2006; Wang *et al*., 2004). However, machining accuracy and stability of these machine tools should be enhanced.

Machining system of 4-axis ultra-precision lathe

Overall arrangement of 4-axis ultra-precision lathe: Traditional precision NC lathes have three axes, including spindle (C) and two translational axes (X/Z) in horizontal direction. When ultra-precision optical die with higher accuracy and complex curved surface with higher geometrical accuracy are needed, traditional precision 3-axis NC lathes cannot meet the need. In this paper, a 4-axis ultra-precision lathe with a rotational axis (B) is developed. By using the B axis of this lathe, real spherical

Corresponding Author: Yang Jinrong, State Key Laboratory of Tribology, Tsinghua University, Beijing, 100084, China

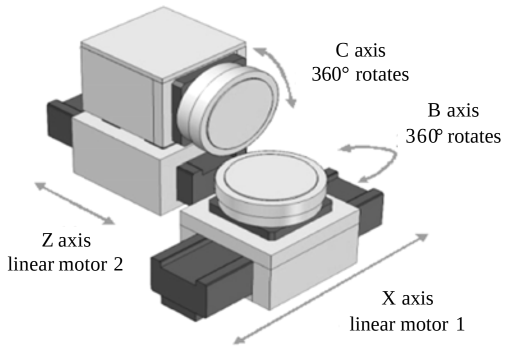

Fig. 1: Overall arrangement of 4-axis ultra-precision lathe

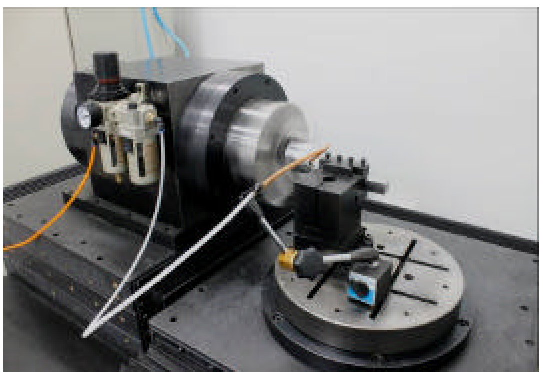

Fig. 2: The real photo of 4-axis ultra-precision lathe

surface and complex curved surface with higher machining accuracy can be acquired.

As shown in Fig. 1, this ultra-precision lathe adopts T shaped layout, the X axis and Z axis of which are separated. The structure makes the overall rigidity of the lathe satisfying and the control of the lathe relatively easy. The X and Z axes lie on the marble bed supported by four shock-absorbing air bearings. The spindle box is laid on the Z axis slide carriage, while the B axis is laid on the X axis slide carriage. The C axis is a kind of high-power motorized spindle with scaling function and the X and Z axes are driven by linear motor, the full closed loop feedback device of which is a linear grating with nanometer level resolution. The real lathe is shown in Fig. 2.

Structure design of key parts: The spindle of ultra-precision lathe directly supports the motion of workpiece or cutting tool, so the rotary accuracy of spindle directly affects the machining accuracy of workpiece. Therefore, the spindle is the most important part of ultra-precision lathe and the accuracy of lathe can be evaluated by the accuracy and characteristics of spindle. At present, aerostatic or hydrostatic spindle is generally adopted as the high-speed rotary spindle. The aerostatic spindle has a characteristic of high rotary accuracy, such as Nanoform 250 lathe with accuracy precision less than 0.05μm of Pneumo Corporation. The spindle of the lathe in this paper is driven by KBMS43 fameless motor of Kollmorgen corporation, with positioning accuracy of 5" and extreme speed of 5000 r min^{-1}. The air bearing of the spindle employs double semi-sphere structure which equals radial bearing and axial bearing and can self-align in order to achieve high rotary accuracy of 0.05 μm. This kind of air bearing has a fine dynamic characteristics and a long lifetime of high accuracy and has no vibration.

In generally speaking, there are two types of ultra-precision drive: direct drive and indirect drive. Direct drive mainly employs linear motor which decreases errors produced by driving medium and has a fine dynamic characteristics and simple mechanism and low-friction. This lathe is suitable to machine workpiece with medium and small caliber and because of small load and travel distance in the machining process, the linear motor of Kollmorgen Corporation is chosen as the direct drive device. The guide is design to be a plane, enclosed air guide. The bearing part is flat, so the supporting rigidity is high and there is almost no heat produced. However, it is important to keep the surface of guide dust-free. The distance between air guides is about 10μm or more as large as the dust which cannot be seen by naked eyes. This tiny dust which cannot be removed in clean room, will cause damage to surface of the guide when falling into the air guide. Thus, the X and Z guides are sealed up by guards. The straightness error and displacement resolution of X and Z guide is respectively 0.15 μm/200 mm and 2 nm.

The diameter of the horizontal rotary worktable of B axis is 340 mm. There is a T shaped groove on the worktable which can clamp certain kinds of tool holder. Certain kinds of complex curved surface can be turned when fully applying the rotation of B axis. Rotary worktable similar to spindle, employ embedded motor as direct drive device and air-float structure as bearing part. A high accuracy circular grating with displacement resolution of 0.036? is used to realize positioning detection and scaling for worktable.

Open NC system: The open NC system-PA800 LW is applied in the lathe which is capable of high programming resolution and is build based on PC operating system-Windows XP. For the motion control and logic control

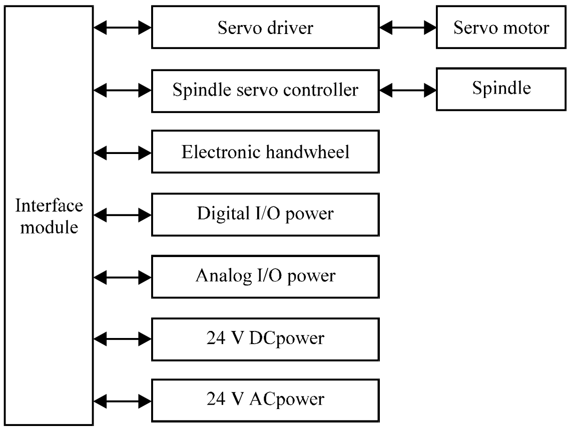

Fig. 3: PA NC function Interface Single point diamond turning experiments of ultra-precision lathe

Fig. 4: Workpiece 1 (large flate surface)

with high real-time requirement, CNC software embedded in PA real-time core runs which directly control related hardware equipment. For low real-time task, such as HMI input, operating system works and PLC controls CNC system via specific interface.

Because the motion control and logic control are completed by PA open NC system, the hardware includes industry PC, display, NC operating panel, interface module and so on. The component-based interface module is connected to industry PC via PA Bus. Based on user's requirements, function of controlling more axes and I/O interface can be realized, as shown in Fig. 3. PA NC

Fig. 5: Workpiece 2 (spherical surface)

system PA consists of HMI module for HMI control, CNC module for NC control and PLC module for PLC control. These three modules offer open interface for secondary development based on the demands of users.

In order to verify the extreme performance of the lathe and whether the accuracy of the lathe keeps consistent and vibration occurs in the machining process, a large flat surface is machined with nature diamond (cutting edge radius R = 2 mm) and the cutting parameters are: Spindle speed is 800 rpm, feed rate is 6 mm/min and cutting depth is 2 μm, as shown in Fig. 4. After machining, the roughness Ra of the workpiece is 5 nm. Semi-sphere is turned so as to evaluate the numerical fitting performance and interpolation accuracy of the lathe and the cutting parameters are: Spindle speed is 1000 rpm, feed rate is 4 mm/min, cutting depth is 1.5 μm and the spline fitting distance is 1.5 μm. As shown in Fig. 5, a mirror surface is obtained.

Complex curve surface is machined with nature diamond (cutting edge radius R = 2 mm), to verify the capability of machining complex curve surface and the overall performance of the lathe and the cutting parameters are: Spindle speed is 1000 rpm, feed rate is 8 mm/min and cutting depth is 3 μm and the oil mist is used as lubrication. As shown in Fig. 6a, b (measured by white light interferometer), the roughness Ra of the workpiece is 9 nm after machining.

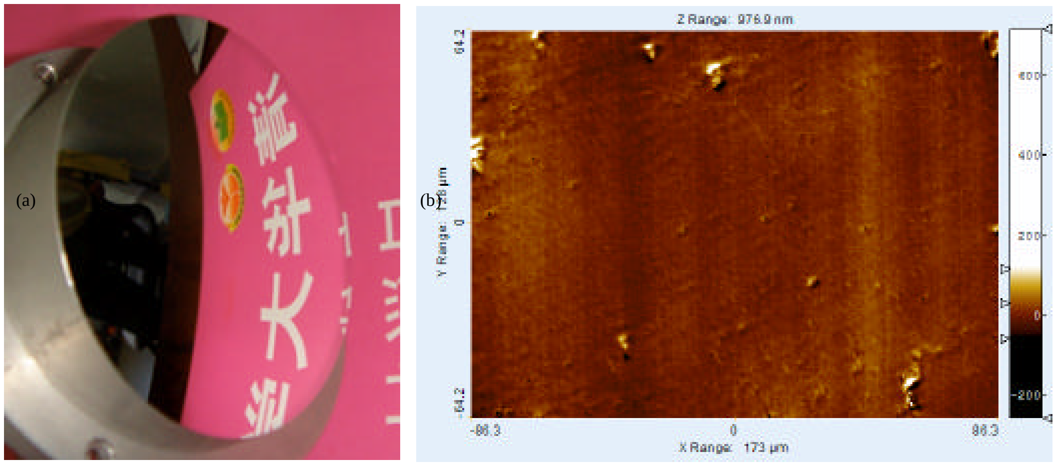

Fig. 6(a-b): Workpiece 3 (complex curved surface) (a) Complex curved surface and (b) Test photo by white light interferometer

SUMMARY

- A small scale 4-axis ultra-precision lathe is developed, to which T shaped layout, air guide and linear motor as direct drive type is applied; Open PA NC system was adopted and the straightness error of linear guide is 0.15 µm /200 mm and the displacement resolution of X/Z axis is 2 nm
- By using single point diamond cutting tool, a flat surface with a diameter of 280mm is machined, the roughness of which is 5nm. Spherical surface and complex curve surface are turned and mirror surfaces were obtained

ACKNOWLEDGMENT

The authors wish to acknowledge the financial supported by Beijing Natural Science Foundation (3131003).

REFERENCES

Dong, J., 2010. Precision and ultra-precision machining equipment: Current status and future solutions. OME Inform., 27: 1-9.

Lee, W., S. To and C. Cheung, 2005. Design and advanced manufacturing technology for freeform optics. The Hong Kong Polytechnic University, Hong Kong, China.

Li, G., S. Dong, J.H. Zhang, H.F. Wang and S.G. Zhang, 2006. A large-scale aspheric surface ultra-precision hybrid machine tool. Nanotechnol. Precision Eng., 4: 75-78.

Li, S. and Y. Dai, 2003. New development of the ultra-precision machine tool. Chin. J. Mechan. Eng., 39: 7-14.

Li, S. and J.Z. Zhu, 2000. Development of ultra-precision manufacturing and its key technologies. Chin. J. Mechan. Eng., 11: 177-179.

Li, Y., X.Y. Zhang and X.D. Xie, 2010. Development of ultra-precision machine for large-sized mirror surface. Nanotechnol. Precision Eng., 8: 428-432.

Taniguchi, N., 1983. Current status in and future trends of, ultraprecision machining and ultrafine materials processing. CIRP Annals, 32: 573-582.

Wang, G., S. Li and Y. Dai, 2004. Design method and accuracy analysis of aspherical optical compound machine tool. China Mechan. Eng., 15: 99-102.

Yuan, Z., 2006. New developments of precision and ultra-precision manufacturing technology. Tool Eng., 40: 3-