A Newly Developed Ulptaprecision Machine Tool "ANGEL"

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Abstract

Demands for fabricating micro- and nano-structured surfaces have increased in the advanced science and engineering fields. This paper presents a newly developed ultraprecision machine tool for enabling nano-machining over large work area. In order to remove all the existing error factors from the structure, the machine tool developed is of a perfect non-contact structure excluding the machining point. The performance evaluation results confirm that the developed system provides superior performances for nano-machining.

1 Introduction

Demands for ultraprecision machining process have increased in the advanced science and industrial fields. In particular, structured surfaces with micro- and nano-patterns have recently been required for various industrial sectors. In order to meet the requirements, it is necessary and indispensable to realize an ultraprecision machine tool with both nanometer order machining accuracy and a large work area. In our research project, therefore, an ultraprecision machine tool is newly developed for nano-machining over large work area. The developed machine tool is composed of some originally designed structural components such as an X-Y planar nano-motion table system and an air turbine driven-aerostatic spindle system [1-4]. This paper describes the basic concept of ultraprecision machine tool and the structural components. In addition, typical examples of performance evaluation are also described.

2 Design concept of the newly developed machine tool

Figure 1 shows a basic structural concept of the advanced nano-pattern generator with large work area named ANGEL. The main body of ANGEL was installed in a temperature-controlled enclosure and supported by an active pneumatic vibration isolation system. An X-Y planar nano-motion table system and a Z axis nano-motion

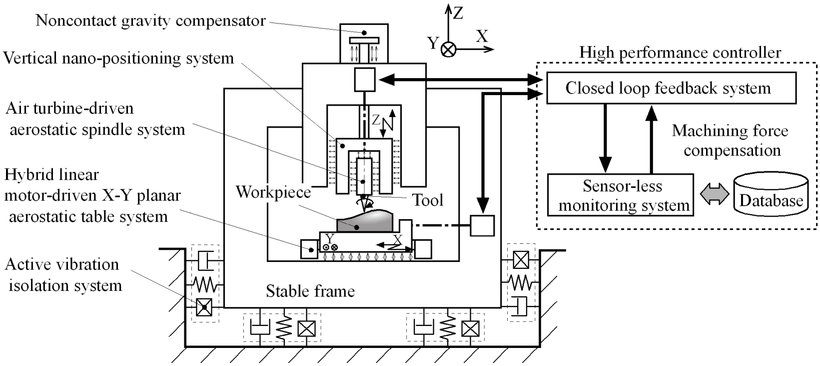

Fig.1 : Design concept of the developed ultraprecision machine tool “ANGEL”

mechanism are supported by aerostatic bearings and driven by voice coil motors in a perfect non-contact condition to eliminate nonlinear phenomena such as friction or stick-slip. In addition, the moving mass of the Z axis nano-motion stage is supported by a gravity compensator of noncontact type. Hence, the cutting point between a tool and a workpiece is only one contacting point on the machine tool. Each linear motor is located at the center of gravity of the moving table to eliminate angular excitation. In order to realize a stable machine structure, the fundamental structural components are arranged symmetrically with respect to each driving axis so as to eliminate thermal error. Figure 2 and Table 1 show the appearance of ANGEL and the specifications of the machine tool, respectively.

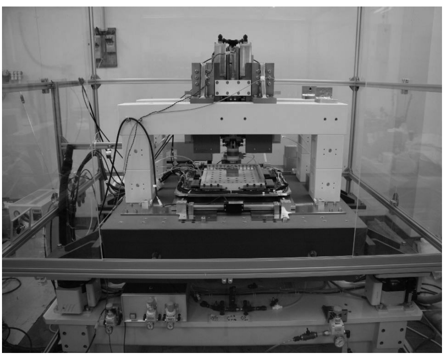

Fig.2 : Appearance of “ANGEL”

Table 1**:** Specifications of the system

Machine size	H : 1450mm W : 1640mm D : 1000mm
Total mass of machine	1350 kg
Stroke	X,Y : 180mm Z : 70mm
Feedback resolution	X,Z : 0.63nm Y : 0.31nm
Max. feedrate	X,Y : 250mm/s Z : 150mm/s
Spindle rotational speed	~ 60,000rpm

Positions of the X-Y planar nano-motion table and the Z-axis stage are directly measured with laser interferometers and are controlled by a high performance controller with a sensor-less monitoring system which is based on a disturbance observer. Because the developed positioning systems have no nonlinear behavior the disturbance observer can precisely estimate the cutting force without force sensors, and it enables the controllers to compensate the cutting force during the machining.

3 Performance evaluation

In order to evaluate the performance of the machine tool, some positioning experiments were performed under a free load condition. Figure 3 shows a 1nm stepwise positioning of the X-Y planar nano-motion table and the Z-axis stage. As shown in Fig. 3, a clear stepwise nano-motion can be observed. Figure 4 shows a result of circular motion in the X-Y plane with a diameter of 100mm and a feed speed of 62.8mm/s. There was no quadrant glitch in the circular motion and the maximum radial error during the driving was less than 4.5nm. The moving table and the stage are supported in a noncontact condition, thus nonlinear error factors such as backlash and stick-slip phenomenon could be eliminated in nano-motion.

To evaluate basic machining capability of the machine, some cutting experiments were performed. A single crystal diamond tool was fixed on the vertical table system, while a workpiece of oxygen free copper was fixed on the X-Y planar motion table system. Feeding and pick-feed motion were given by the X-Y planer nano-motion table system, while the depth of cut was given by the Z-axis stage. Figure 5 shows a typical example of machined surface observed with a scanning probe microscope. As shown in this figure, a clear stepped shape with a 50nm height could be observed. These results confirmed that the developed table systems equipped with both the sensor-less monitoring and the compensating functions has high stiffness and high stability for achieving nano machining capability.

4 Conclusion

This paper described the newly developed advanced nano-pattern generator with large work area named “ANGEL”. The performance evaluation results confirmed that the developed machine tool provides a machining capability for fabricating nanometric structures on the objective workpiece surfaces.

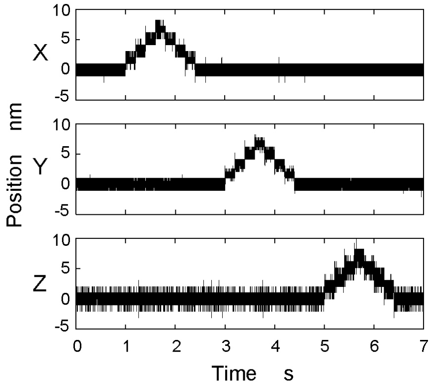

Fig.3 : 1nm stepwise response

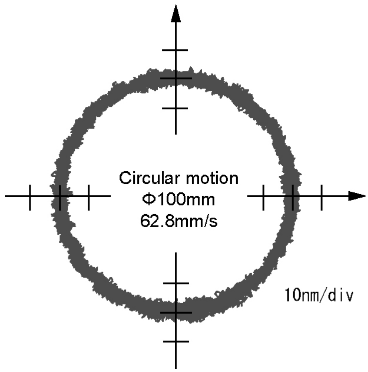

Fig.4 : Circular motion test of X-Y table

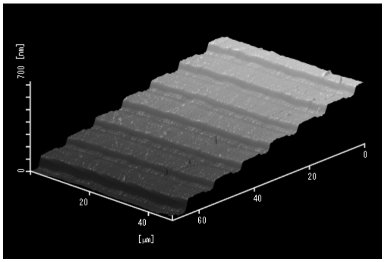

Fig.5 : 50nm stepwise surface

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