Three-dimensional nano-positioning system for compact CMM

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Abstract

A three-dimensional nano-positioning system for a compact coordinate measuring machine (CMM) with the measuring range of 10 mm × 10 mm × 10 mm and the measuring resolution of 1 nm was developed. This system is composed of a planar nano-motion table system driven by voice coil motors (VCMs), a vertical nano-motion system driven by a hybrid actuator and a probe holder that can attach scanning probe microscopy (SPM) probes. Performance evaluation results confirm that this system has high positioning accuracy and high stability.

1 Introduction

Demands for a compact coordinate measuring machine (CMM) which can measure three-dimensional micro-geometries over a large area increased [1]. In order to meet such demands, a three-dimensional nano-positioning system with high positioning accuracy and large measuring range is required. Then, this study presents a newly developed three-dimensional nano-positioning system for a compact CMM.

2 Structural configuration of a nano-positioning system for a compact CMM

2.1 Proposed concept of a compact CMM

Figure 1 shows a proposed concept of an innovative compact CMM. Measurement of a 3D profile can be made possible by controlling the position of the probing system to keep the distance constant between the probe and the specimen surface during an X-Y scanning. The X-Y planar table and the Z-axis positioning system are guided by aerostatic bearings. In order to enlarge the stroke limitation of a piezoelectric actuator (PZT) for the Z-axis driving, a main body is driven by the voice coil motor (VCM) with a millimeter stroke. In addition, the Z-axis positioning system has a gravity compensator using a vacuum cylinder. Then, the X-Y planar table and the Z-axis positioning system are guided and driven in a perfect noncontact condition, and various nonlinear phenomena can be removed from the machine. Furthermore, in order to improve stability, the overall positioning system is installed in a temperature-controlled enclosure and the machine base is supported by an active vibration isolation system.

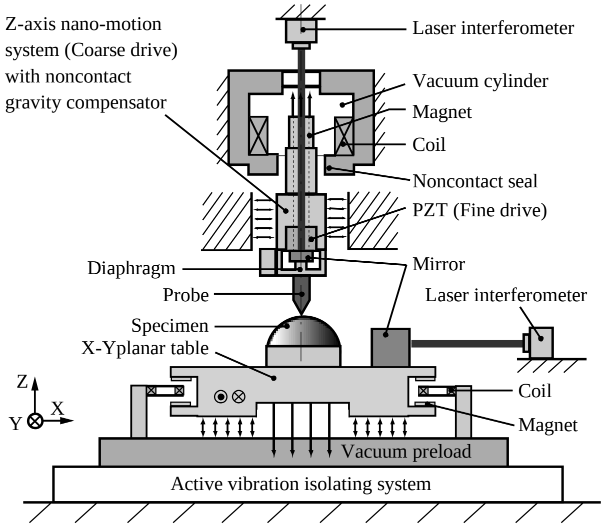


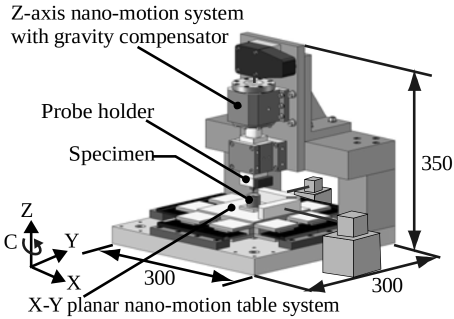
Figure 1: Structural concept of the compact CMM

2.2 A three-dimensional nano-positioning system developed

Figure 2 shows the structure of the three-dimensional nano-positioning system.

The X-Y planar table levitated with four porous air bearings can be driven by eight VCMs. The table position on the X-Y plane is measured by a laser interferometer and two plane mirrors fixed on the table. In this system, the full closed-loop control systems with the interferometer feedback are used together with a proportional–integral–derivative (PID) controller and an acceleration feedforward compensator.

The Z-axis nano-motion system is composed of a voice coil motor, a noncontact gravity compensator, a PZT, a laser interferometer and a probe holder. By a through hole at the center of the vertical moving body, the position of the probe can be measured directly. Scanning probe microscopy (SPM) probes such as scanning tunneling microscopy (STM) probes or atomic force microscopy (AFM) probes can be attached to the probe holder. Figure 3 shows a block diagram of the Z-axis nano-motion control system. Fine driving mechanism and coarse driving mechanism are driven simultaneously by the full closed-loop control system with the interferometer feedback.



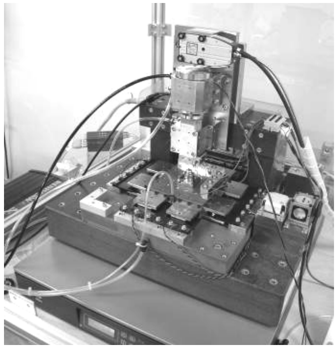


Figure 2 (a): Structure of positioning system (b): Photograph of positioning system

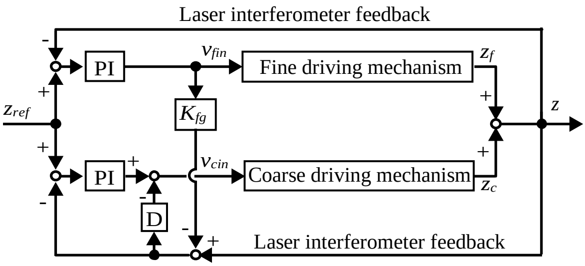


Figure 3: Block diagram of the Z-axis nano-positioning system

3 Performance evaluation of the nano-positioning system

In order to evaluate performance of the nano-positioning system developed, positioning experiments were conducted. Figure 4 shows the table response for stepwise positioning (1 nm on each axis) in 3 axes simultaneous control. The positions of each axis were measured by internal laser interferometers. A clear 1 nm stepwise positioning can be observed on each axis. As the results, it was clear that this system has high positioning resolution of 1 nm.

In addition, the stability of developed system was evaluated. A STM probe was used as the SPM probe and the Z-axis was controlled to keep tunneling current constant for 60 minutes. An oxygen-free copper was used as the specimen. The displacement of Z axis was measured by the internal laser interferometer. The temperature variation around the system was within ± 0.1 degree during the measurement. Figure 5 shows the response for the tunneling current feedback. The difference of the Z position of 60 minutes is approximately 50 nm, and the tunneling current is kept constant successfully. These results show that the system has high stability.

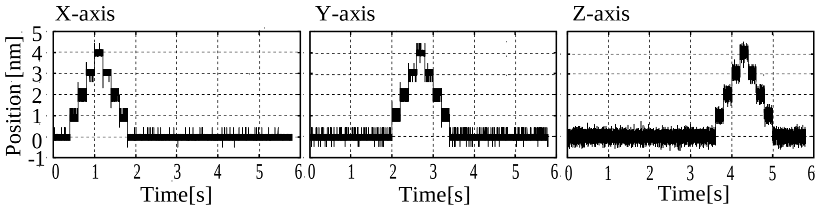


Figure 4: Response for stepwise positioning

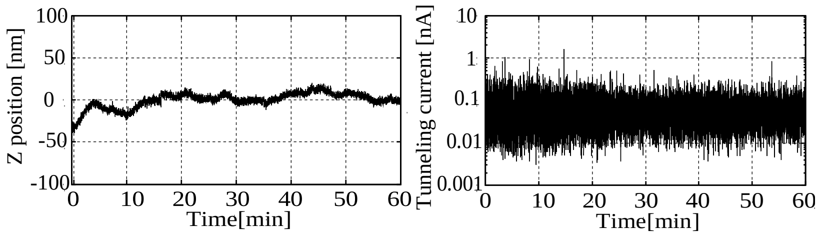


Figure 5: Response for the tunneling current feedback

4 Conclusions

This paper presents a newly developed three-dimensional nano-positioning system for compact CMM with the measuring range of 10 mm × 10 mm × 10 mm and the measuring resolution of 1 nm. As the results of performance resolution, the following conclusions could be drawn:

(1) The structural concept of a compact CMM with the measuring range of 10 mm × 10 mm × 10 mm and the measuring resolution of 1 nm was shown and the three-dimensional nano-positioning system was developed for the compact CMM.

(2) The performance evaluation results confirmed that the three-dimensional nano-positioning system achieves high positioning resolution and high stability.

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References

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