PICOMETER POSITIONING SYSTEM USING AEROSTATIC GUIDEWAY AS MOTION-REDUCTION MECHANISM

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1. Introduction

Precision positioning is one of the basic functions of machine tools and measuring instruments used in the field of nanotechnology. Positioning resolution of these machines should be less than one nanometer. In the present paper, a picometer positioning system is proposed, where the table of an ultraprecision machine tool is positioned with 10pm of resolution. The proposed picometer positioning system uses an aerostatic guideway with an Active Inherent Restrictor (abbreviated as "AIR"). The AIR was invented by the authors for improving the stiffness and the rotational accuracy of air-bearing spindles [1]. A piezoelectric transducer incorporated into the AIR controls the restriction gap on the bearing surface, then the position of the machine table. Owing to aerostatic mechanism, the table displacement can be much less than the deformation of the transducer; therefore, the aerostatic guideway with the AIR acts as motion-reduction mechanism. Characteristics of the proposed positioning system such as positioning resolution and dynamic response are reported.

2. Motion-Reduction Mechanism using Aerostatic Guideway

Figure 1 shows the proposed picometer positioning system. A ceramic machine table (size: 300mm x 350mm x 100mm, mass: c.50kg) of an ultraprecision machine tool [2] is guided by an aerostatic guideway in X direction (normal to the paper). This X-table can also be positioned in Z-direction (horizontal, cutting direction) by the Active Inherent Restrictor (AIR) incorporated into the aerostatic guideway. A positioning instruction output from a microcomputer is converted into the supply voltage to the piezoelectric transducer (PZT) in the AIR. The X-table moves according to the deformation of the PZT. The table movement in Z-direction is detected by a fiber optic sensor and fed back to the computer. Thus a closed-loop control system is completed. Then the computer outputs the instruction for correcting the table position. The movement of the table is monitored by an FFT analyzer.

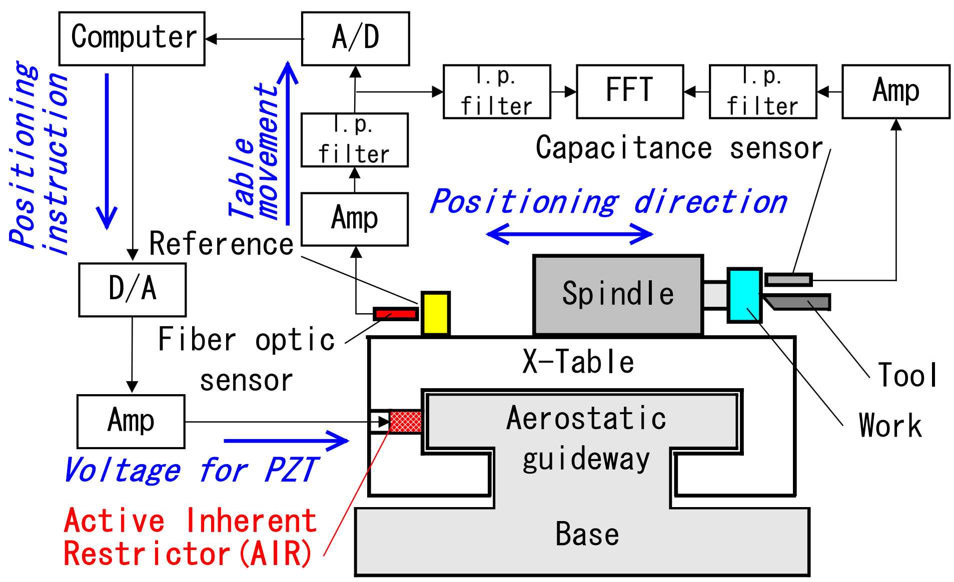
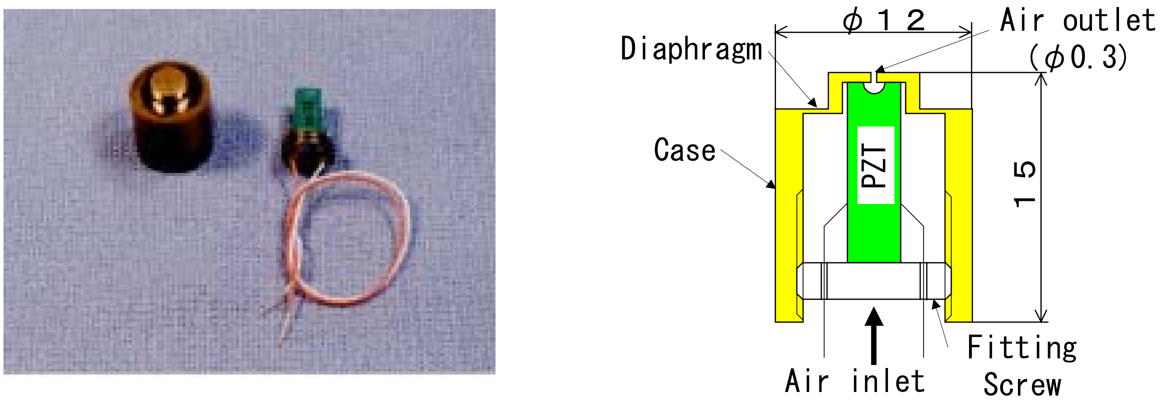


Fig. 1 Ultraprecision positioning system using aerotatic guideway



(a) Piezoelectric transducer and diaphragm case **(b) Cross section of assembled AIR unit**

Fig. 2 Unit and elements of Active Inherent Restrictor (AIR)

The elements and the assembled view of the AIR are shown in Fig. 2; the AIR unit consists of a piezoelectric transducer (PZT) and a diaphragm case that has an air outlet. The hole is small enough to function as an orifice when the transducer is embedded in the bearing surface. The positioning mechanism using the AIR is shown in Fig. 3. A table is supported by an aerostatic guideway with an inherent restrictor. Orifice area of the inherent restrictor formed on the bearing surface is $\pi d h_d$, where, d is the diameter of the air outlet and h_d is the restriction gap that can be controlled by PZT. When the length of PZT decreases by Δh_d, the airflow rate and the pressure on the bearing surface increases. Then, the air film thickness h increases by Δh, and the table moves upward.

Owing to aerostatic mechanism, the table displacement Δh in Z-direction can be much less than the deformation of the transducer Δh_d. Figure 4 indicates an experimental relationship between Δh_d and Δh: full stroke of the piezoelectric transducer is 3.5 µm, while the maximum movement of the table is 110nm. This means that the aerostatic guideway with the AIR acts as motion-reduction mechanism. The reduction rate shown in Fig. 4 is about thirty.

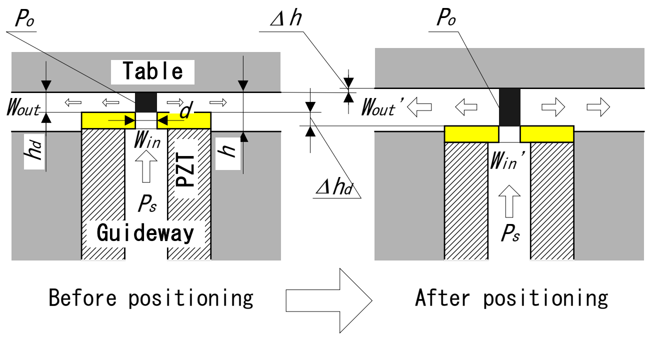


Fig. 3 Motion reduction mechanism of AIR

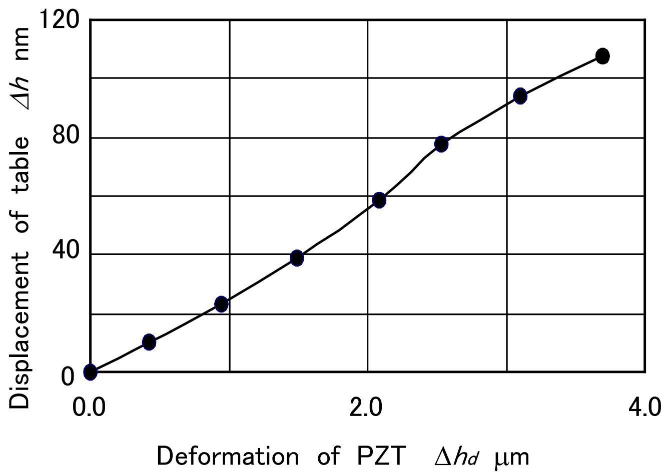


Fig. 4 Characteristic of motion reduction by AIR

3. Dynamic Response

Figure 5 shows a dynamic step response of the positioning system, where the width of the step is 10nm. From the rising of the curve, the slew rate is calculated to be about 4.5nm/ms. Settling time, the time for completing the step movement, is about 20ms. The frequency response of the

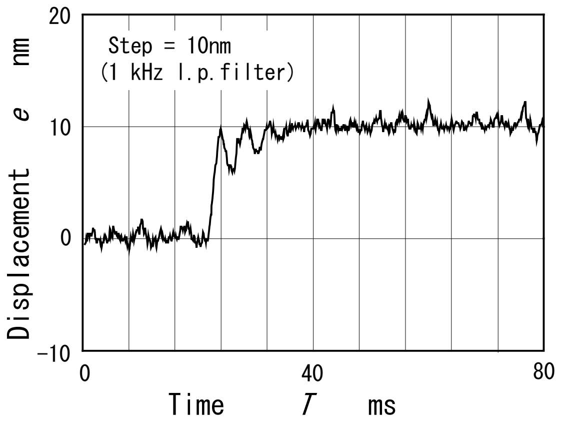


Fig. 5 Step response of the system

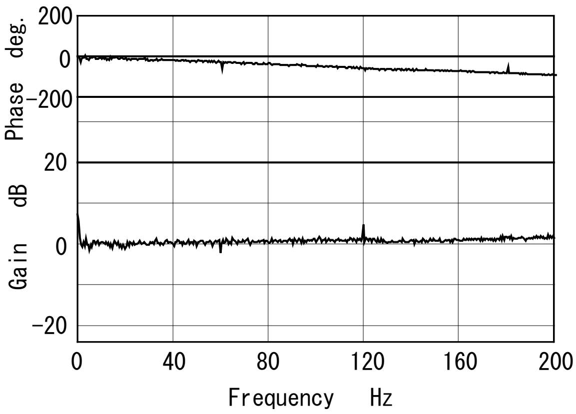


Fig. 6 Frequency response of the system

system is shown in Fig. 6, where the amplitude of sinusoidal instruction is 5nm. As the frequency increases, the amplitude of the table vibration slightly increases. Phase lag also increases, however, the phase lag at 50Hz is only 20deg. Therefore, maximum controllable frequency is at least 50Hz. In spite of large phase lag, the amplitude of vibration does not reduce at 200Hz. The response for a series of rectangular positioning instructions is also examined. Maximum pulse rate that the X-table can follow after is about 25HZ.

4. Positioning Resolution

Results of static step positioning with various step widths (100pm, 50pm, 20pm and 10pm) are shown in Fig. 7. Steps of the same width are repeated five times in one direction then in the reverse direction. Low pass filter is used to decrease noise. Steps larger than 20pm are clearly resolved. Steps of 10pm are degraded by noise and not so clear as others, however, every step can be recognized. Therefore, the positioning resolution of this system is considered to be 10pm.

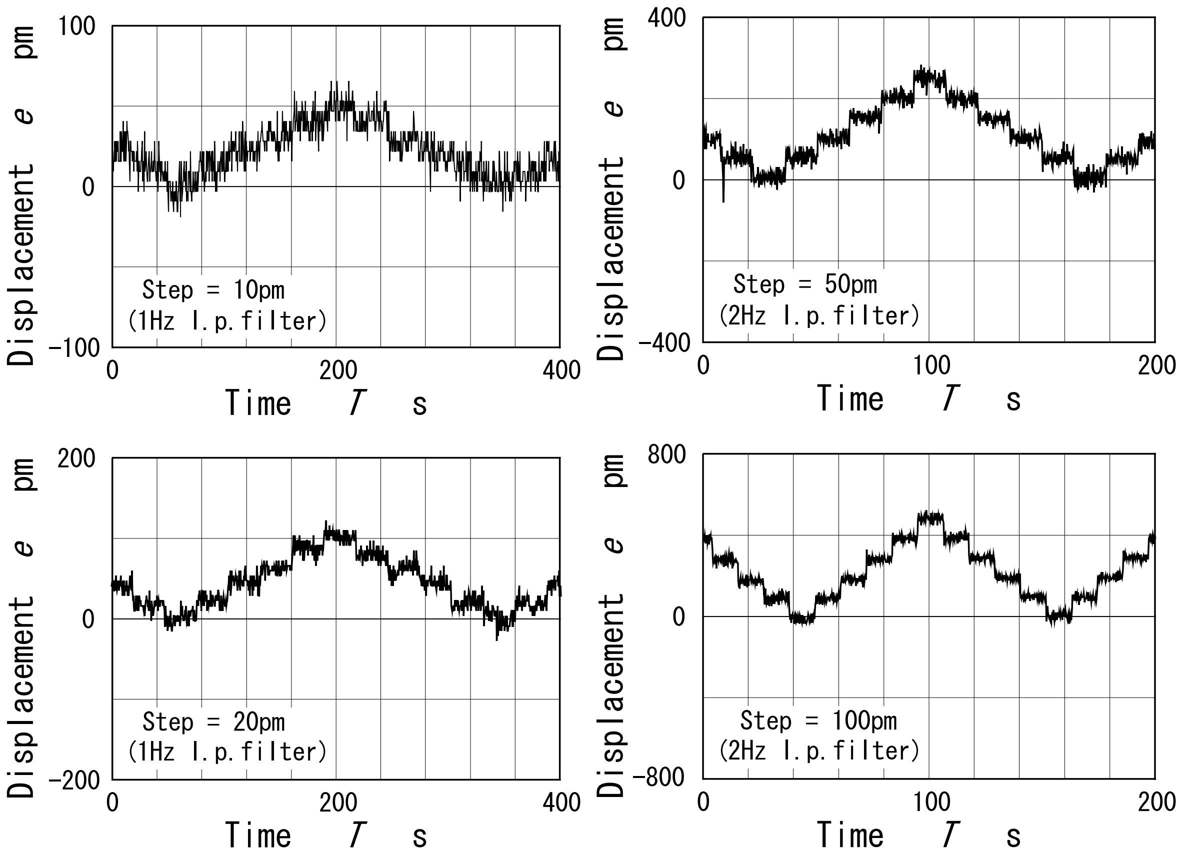


Fig. 7 Picometer step positioning (step width: 10pm, 20pm, 50pm and 100pm)

5. Micro Step Cutting

As shown in Fig.1, an aluminum alloy mounted on the X-table can be turned. During single point diamond turning, micro steps can be made on the turned surface by positioning the X-table in the cutting direction. Figure 8 shows the table displacement measured at the reference point for the positioning system (a) and the cutting point (b). Step positioning of 10nm is repeated five times then reversed. At the cutting point, the width of step is about 16nm, which is larger than at the reference point. This is because some rotation of the X-table occurs. Three-dimensional expression of the turned surface is shown in Fig. 9, where, about 18nm width of steps can be recognized. Therefore, this positioning system can also be used as a micro cutting device.

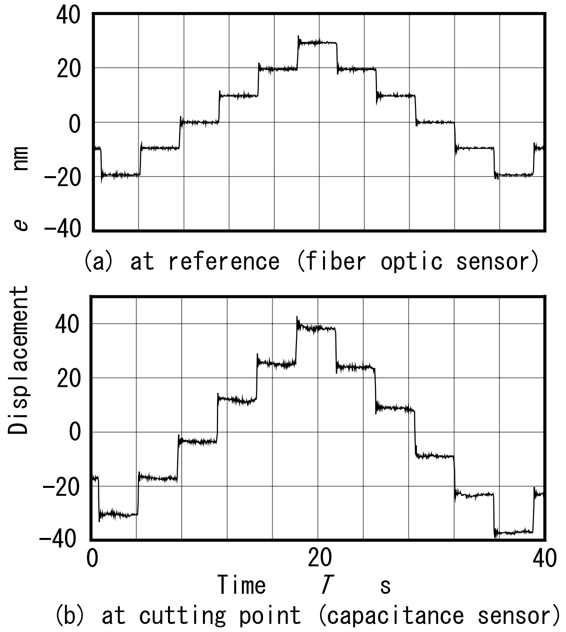


Fig. 8 Cutting of micro step using positioning system

6.Conclusions

The effect of the proposed motion-reduction mechanism using the active aerostatic guideway on the characteristics of the positioning system is analyzed and following results are obtained:

(1) The motion-reduction mechanism effectively reduces the deformation of the piezoelectric transducer. Measured reduction rate is about thirty.

(2) The dynamic step response indicates that the settling time is about 20ms and the frequency response indicates that the maximum controllable frequency is about 50Hz.

(3) Stroke (maximum movement of the table) is only about 100nm, however, static step positioning in various step widths shows that the resolution of the positioning system is 10pm.

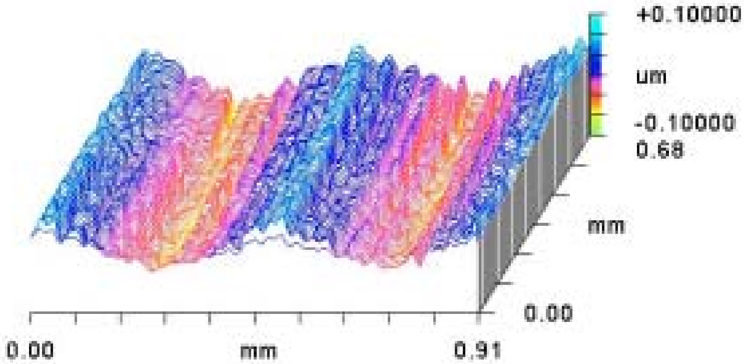


Fig. 9 Micro steps turned on aluminum alloy

Thus, picometer positioning resolution is realized. Therefore, this picometer positioning system using the proposed motion-reduction mechanism will be useful in the field of nanotechnology.

References

[1] H. Mizumoto, et. al., Precision Engineering, Vol.19, No.2/3, pp141-146 (1996).

[2] H. Mizumoto, et. al., Proceedings of 1st euspen, Vol.1, pp28-31 (1999).