https://doi.org/10.20965/ijat.2009.p0223

**Editorial for Special Issue**

# Special Issue on Precision and Ultraprecision Positioning

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I have been the chairman of the technical committee of ultraprecision positioning at the Japan Society of Precision Engineers (JSPE) from 1993 to 1997. In November 2008, the 3rd International Conference on Positioning Technology (ICPT) was held in Shizuoka, Japan. After the conference I together with Dr. Sadaji Hayama, an adviser of the journal editorial board, asked by mail the most significant presenters and members of the technical committee of ultraprecision positioning if they are willing to contribute their papers for this special issue. As a result, we received more than 20 manuscripts, among which 2 development reports, 2 reviews, and 14 papers have been selected for publication in this journal. The contents of these papers relate mainly to the nano/subnanometer positioning technology, new control methods for ultraprecision positioning, guide way for precision positioning, positioning for ultraprecision machining, new hard disk drive method, etc. I would like to express my sincere gratitude to the authors for their interesting papers on this issue and I also would like to deeply thank all the reviewers and editors for their invaluable effort.

## 1. Demarcation Between Precision Positioning and Ultraprecision Positioning

The Technical Committee of Ultraprecision Positioning (TCUP) has had a poll on Ultraprecision and Ultraprecision technology to the randomly selected members of Japan Society for Precision Engineers (JSPE) every four years since 1986 [1]. Results indicate that most respondents felt that the maximum allowable positioning error and image resolution was 1 $\mu$m for precision positioning and 10 nm for ultraprecision positioning.

After 2004, most respondents appeared to view 0.1 nm as the demarcation line between the precision positioning and ultraprecision positioning.

## 2. Know-How for Achieving Ultraprecision Positioning

The champion device in ultraprecision positioning is always the stages of demagnification exposure devices for semiconductors. The exposure method using stages have advanced from 1980s steppers shown in **Fig. 1(a)** to today's scanning stages with the increasement of LSI capacity in achieving higher processing as shown in **Fig. 1(b)**. The stepper consists of X and Y stages.

The XY stages in the 1980s consisted of a DC servomotor, either a ball or sliding screw plus a linear guide way consisting of either rollers or a slide guide. Current scanning type consists of a linear motor and pneumatic hydrostatic guide way (**Fig. 1(b)**). Reticle and wafer stages travel in opposite directions and the relative positioning error is about 1 nm.

Ultraprecision positioning of sub-$\mu$m accuracy is now achieved either by an AC servomotor and a ball screw or by using a linear motor.

### 2.1. Achieving High Accuracy and High Resolution

Achieving high positioning resolution and accuracy with less than 0.1 $\mu$m generally depends on three factors:

(1) Displacement sensors for feed-back

(2) Mechanical structure

(3) Control, including software

Ultraprecision positioning is possible only when these three factors are well coordinated.

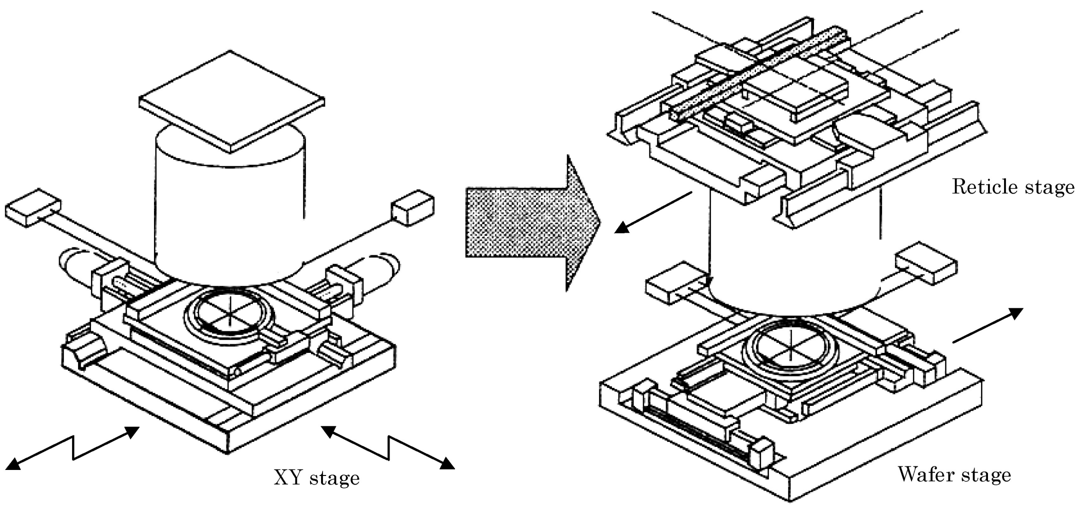
**(1) Displacement Sensors**

Ultra-precision positioning requires high-performance displacement sensors. About 10 sensor manufacturers in Japan alone currently achieve resolution under 1 nm [3]. To achieve higher resolution, laser interferometers must operate in thermostatic chambers controlling or monitoring temperature, humidity, and atmospheric pressure. Great effort is required to minimize or eliminate air turbulence and inhomogeneous atmosphere temperatures in the laser beam path. To achieve nm level resolution, operations must be conducted in a vacuum.

Linear encoders, although somewhat less accurate than laser interferometers, are used in over 50% for ultraprecision positioning devices in Japan and their market share continues to grow, according to the 2006 TCUP poll. Analog sensor performance in detecting microscopic displacement is steadily improved. The technical level of precision positioning device is often assessed by how the designer considers Abbe's principle.

**(2) Mechanical Structure**

Overall structural rigidity should be maximized to ensure monolithic construction. Semiconductor aligners



(a) Stepper method (b) Scanning method

**Fig. 1.** Demagnification exposure.

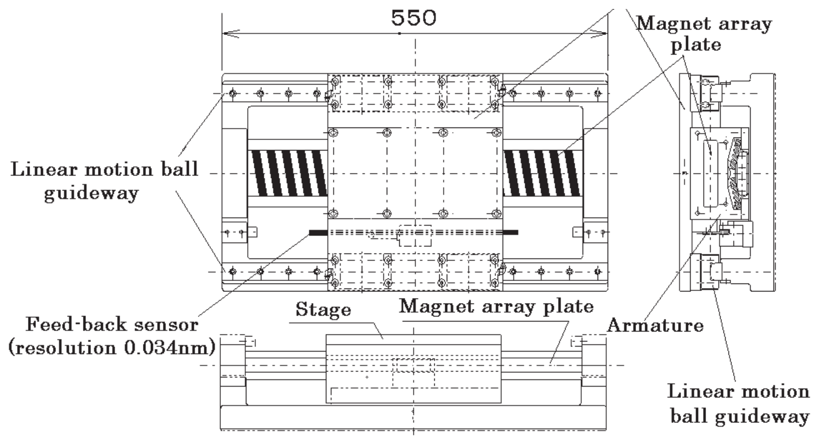



**Fig. 2.** Ultraprecision positionig device driven by new type linear motor (called "Tunnel Actuator," Hitachi Co. Ltd. make).

used in exposure are made from ceramics with a high specific rigidity, i.e., the quotient of Young's modulus divided by specific gravity.

1990s arguments pitting linear actuators against ball screws subsided as their specific advantages and domains of preferred use became established. Linear guide ways using steel balls or rollers are becoming cheaper, and their accuracy and other aspects of performance are improving.

When stage movement is reversed, friction generated by preloads as nonlinear spring behavior which is caused by elastic deformation of balls and race ways over the moving stroke of several tens of $\mu$m, stage vibration is easy to generate. Another disadvantage, called waving, occurs when the table moves up and down at the sub-$\mu$m level perpendicular to the stage travel direction at twice the spacing of the roller separation. It is found out that waving is minimized by crowning roller guide race way. Error due to waving is reduced to less than one tenth of the original error margin [4]. Nonlinear spring behavior is minimized by modifying control method of the positioning device. For longitudinal travel, pneumatic-hydrostatic devices virtually unaffected by friction are an alternative but are prohibitively expensive.

**(3) Control, Including Software**

In precision positioning, control devices and systems have advanced significantly in the last two decades [5], changing from analog to digital with higher sampling frequency. Current digital control enables devices to be operated in conceptually the same way as analog control. TCUP respondents [1] stated that 70% of positioning devices in Japan still depend on conventional control, PID control, with innovative contemporary control theory, fuzzy control, and neural nets, etc. yet to be fully implemented.

### 2.2. Higher Positioning Speed

Higher positioning speed is required, as well as higher positioning accuracy. In scanning **Fig. 1(b)**, maximum stage speed exceeds 2 m/s second and maximum acceleration ranges from 3G to 5G. The corresponding speed and acceleration of the wafer stage is one fourth of these values. At such high acceleration, reaction dampers are used to prevent vibration [2].

About ten years ago, the maximum velocities of positioning stages tended to be limited by the speed of the displacement sensor for feed-back, however at present, it is possible to operate at the range of speed mentioned above. Note that the velocity exceeding 2 m/s is possible even with ball-screw, but noise and microvibration remain a problem.

## 3. Nanometer and Subnanometer Positioning [3, 5-7, 10]

We are pursuing the convergence of the positioning resolution to the fullest extent of the resolution of the displacement sensor for the feed-back. Bulletins [3, 6] have carried reports on experiments attaining resolution for positioning with maximum error below 0.1 nm. We introduce cases of positioning device development at nm and sub-nm resolution using both ball screw [7] and linear motor drives [8]. I would like to introduce a commercialized ball screw drive production of 1 nm resolution [7].

### 3.1. Combination of Ball-Screw and Stepping Motors [7]

The positioning devices have the resolution respectively at 1 nm and 5 nm (the lengths of travelling strokes for the stage are 20 m and 50 mm respectively). Both compensate for the rolling frictions between the ball screw and the roller guide way and for the nonlinear spring behavior at the micro-displacement range through the control of the stepping motors at high, medium and low ranges of speeds. As the dimension of detector of the displacement sensor is very small, we can make the positioning devices smaller. So, it is very strong to external disturbances.

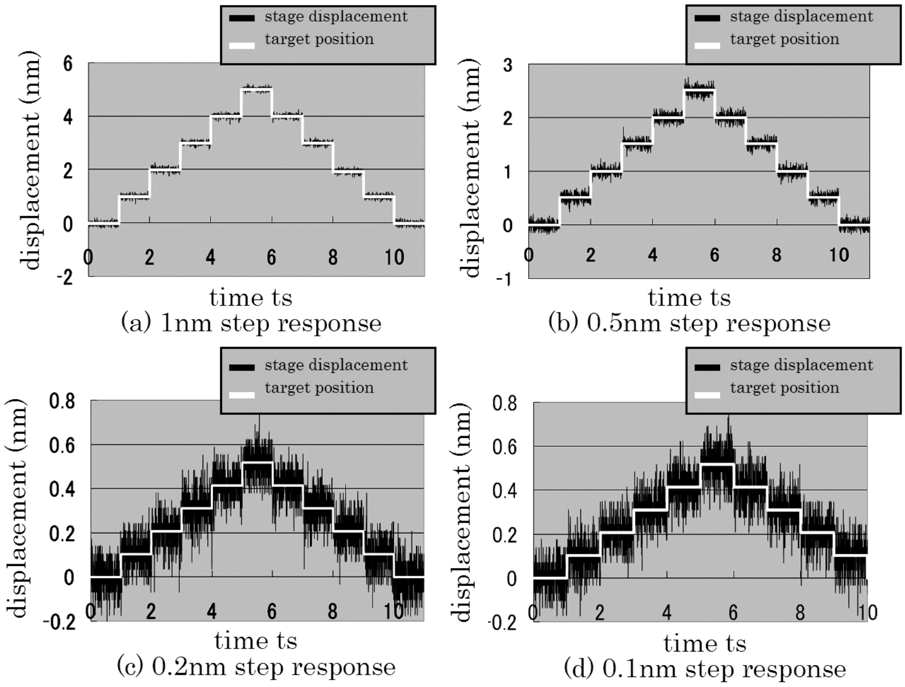



**Fig. 3.** Positioning resolution of ultraprecision device driven by new type linear motor.

### 3.2. New type of Linear Motor Drive [8]

The latest new type of linear actuators, generally referred to as tunnel actuators (TAs) used in ultraprecision positioning devices with a stage stroke of 200 nm (**Fig. 2**) are free from magnetic attractive force between stator magnets and armatures, generating less heat and having other advantages over conventional linear motors with cores.

In experiments using a displacement sensor to adjust feed-back with 0.034 nm resolution and a maximum velocity of 400 mm/s, we use ball guide ways to reduce cost and still achieved a positioning resolution of 0.2 nm (**Fig. 3**) [8]. Experiments confirmed that, to achieve more higher resolution, electric current linear amplifiers are 10 times more effective than PWM as the current amplifier.

## 4. Conclusions

We have discussed how nanometer- and sub-nm level positioning resolution and accuracy became possible, greatly contributing to advances in nanotechnology. Nanometer and subnanometer positioning resolution are currently verified by signals from displacement sensors for feed-back. Considering changes in the positioning of stages, however, such positioning and resolution should be verified by using displacement sensors which are more accurate.

If possible, verification on the resolution and accuracy must be done using a laser interferometer in a vacuum in a temperature-controlled chamber. We feel that positioning resolution should be indicated by signals directly received from sensors without low pass filter.

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