Measurement of straightness of two-dimensional translatory stage

Mitsushi Tominaga [1,#], **Kazuki Fujiyama** [1], **Miyu Ozaki** [2] and **Ryoshu Furutani** [1]

1 Department of Mechanical Engineering, School of Engineering, Tokyo Denki University, Kanda-Nishiki-Cho 2-2, Chiyoda, 101-8457 TOKYO, Japan
2 Department of Robotics and Mechatronics, School of Science and Technology and Future Life, Tokyo Denki University, Kanda-Nishiki-Cho 2-2, Chiyoda, 101-8457 TOKYO, Japan
Corresponding Author / E-mail: 10kmm40@ms.dendai.ac.jp , TEL: +81-3-5280-3455, FAX: +81-3-5280-3571

KEYWORDS : Dimensional Measurement, XY-stage, Straightness, Axis of Motion, Reference Mirror

XY-stage has high positioning accuracy and it is used for manufacturing and measuring precise machine components. The highly precise XY-stage is required for the higher precision of the machine components. To make higher-precision XY-stage, it is necessary to establish methods to measure straightness of the shape of the axis of movement. In order to measure the position of XY-stage, 2 sensors are used in x- and y-direction. These sensors have profile errors of the metrological frame because they measure the displacement from the metrological frame. In nanometer application, it is impossible to neglect the profile error. In measuring the position of XY-stage by the laser interferometer, the shape of the axis of movement and the profile errors of the reference mirrors are included in the measurement result. This study proposes a new method which separates the shapes of the axis from the profile errors of the reference mirrors by numerical calculation and estimates the straightness of the axis. The three reference mirrors were placed in x- and y- direction respectively, two laser interferometers measured the displacement from reference mirrors in x- and y-directions. In this study, we separated the shape of the axis of XY-stage from the profile of the reference mirrors.

Manuscript received: January XX, 2011 / Accepted: January XX, 2011

1. Introduction

XY-stage is used for manufacturing and measuring precise machine components in nanometer application, such as AFM and Photo-microfabrication [1].

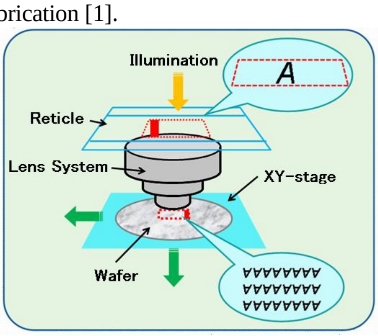
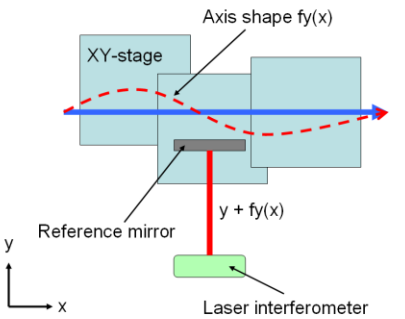


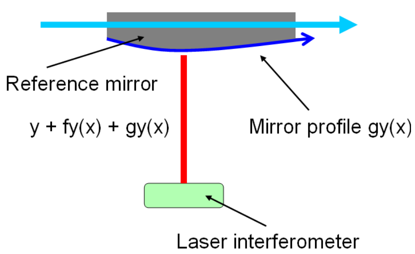
Fig. 1 Application of XY-stage

In order to measure the position of XY-stage, two sensors are used in x- and y-direction. These sensors have profile errors of the metrological frame because they measure the displacement from the metrological frame. In nanometer application, it is impossible to neglect the profile error.

Fig. 2 shows errors of the XY-stage. In measuring the position of XY-stage by the laser interferometer, the shape of the axis of movement and the profile errors of the reference mirrors are included in the measurement result [2, 3]. This study proposes a new method which separates the shapes of the axis from the profile errors of the reference mirrors by numerical calculation and estimates the straightness of the axis with the laser interferometer and three reference mirrors.



(a) Axis shape error



(b) Mirror profile error

Fig. 2 Errors of XY-stage

2. Experiment system

2.1 Schema of the equipments

Fig. 3 shows the experiment system. The x-stage and y-stage are laminated and the reference mirrors are set on the top plate. In this study, XY-stage moves in two directions. The displacement of stage is measured by the sensor in each stage and two laser interferometers set on the metrological frame.

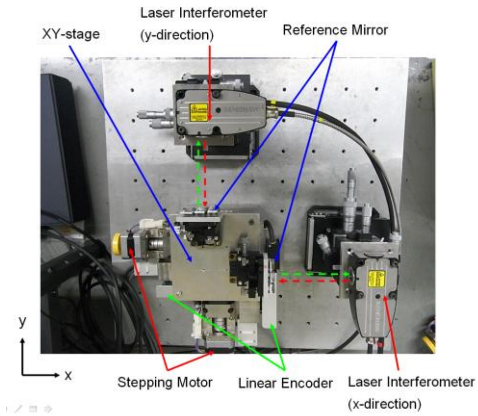


Fig. 3 Experiment system

2.2 XY-stage

Fig. 4 shows the XY-stage. This stage consists of one-dimentional stages, the upper stage is x-stage and the lower stage is y-stage.

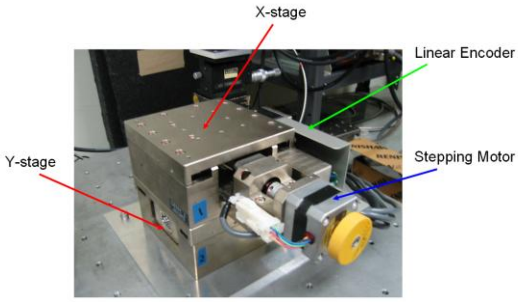


Fig. 4 XY-stage

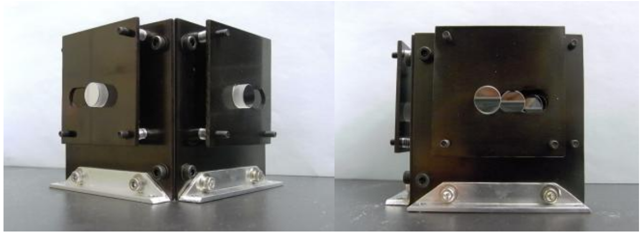
The actuators of these stages are stepping motor and PZT. Positioning accuracy of these stages is ±10 [nm], and the movable range is 30 [mm].

2.3 Laser interferometer

Fig. 5 shows the laser interferometer. Its wave length is 633 [nm], and resolution is 0.395 [nm].

Fig. 5 Laser interferometer

Fig. 6 shows the reference mirrors. It consists of three reference mirrors of which diameters are ϕ10 [mm] and mirror surface unevenness is 1/10 [wave]. So, the maximum range of mirror surface is about 63 [nm].



(a) Over head view (b) Side view

Fig. 6 Reference mirrors

3. Principle

3.1 The conceptual model of XY-stage

Fig. 7 shows the conceptual model of the XY-stage when this stage moves from origin of coordinates to point A.

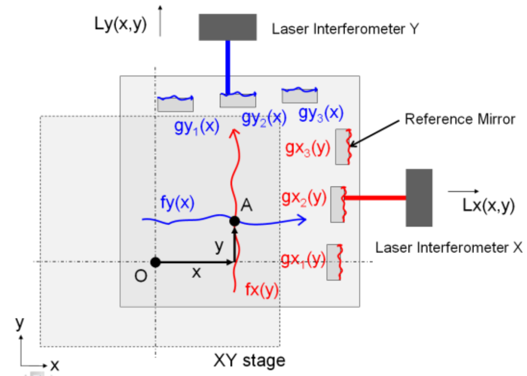


Fig. 7 Model of the XY-stage and definition of parameters

The measuring result by laser interferometer is referred as Lx(x,y), and Ly(x,y). Lx(x,y) and Ly(x,y) are expressed as

$$\begin{aligned} Lx(x,y) &= x + fx(y) + gx_i(y + fy(x)) \\ Ly(x,y) &= y + fy(x) + gy_i(x + fx(y)) \end{aligned} \qquad (1)$$

Table 1 shows parameter definition of Eq(1).

Table 1 Parameter definition

Symbol	Definition
Lx, Ly	Measurement value by the laser interferometer
x, y	Measurement value by the sensor in the XY-stage
fx, fy	Axis shape
gx, gy	Mirror profile
i	Mirror No.

3.2 Mirror model

In this study, gx and gy could be assumed smaller, we put gx and gy into the primary function. As result, Eq (1) is transformed to Eq (2).

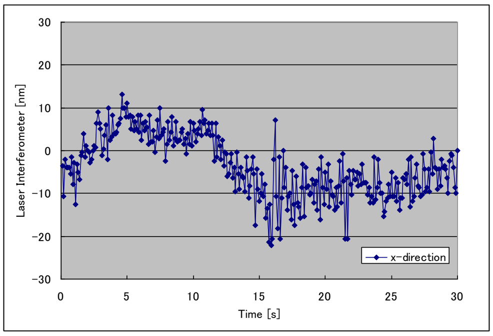
$$\begin{aligned} Lx(x,y) &= x + fx(y) + a_i(y + fy(x)) + b_i \\ Ly(x,y) &= y + fy(x) + a_i(x + fx(y)) + b_i \end{aligned} \qquad (2)$$

(a: slope of the mirror, b: intercept term of the mirror)

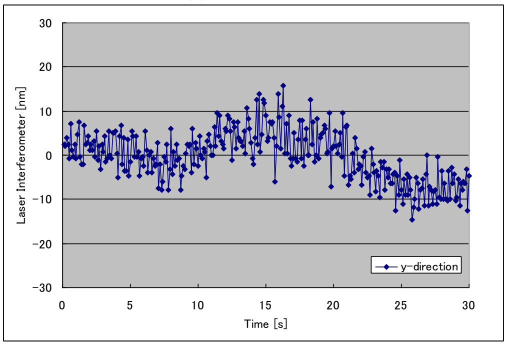
4. Experiment

4.1 Stability of the laser interferometer

As a first step to verify the performance of the laser interferometer, the stability of the signals was measured over 30 [s] while the XY-stage was fixed. Fig. 8 shows the linear stability in two directions.



(a) x-direction



(b) y-direction

Fig. 8 The stability of the laser interferometer

From Fig. 8, PV±SD was 35.2±7.2 [nm] (x-direction) and 30.4±5.7 [nm] (y-direction).

(PV: peak to valley, SD: standard deviation)

4.2 Scanning of the stage displacement

The measurement procedure is shown in Fig.9 and Fig.10 and the following:

1) The stage moves 21steps in the x-direction and the displacements in x- and y- direction measured in each step.
2) The stage returns to the origin in x-direction.
3) The stage moves 1 step in y-direction
4) After measuring block " i ", the stage moves to block " i+1 "

(1step : 10 [μm])

So, the displacement is measured in 21X21X9=3969 points.

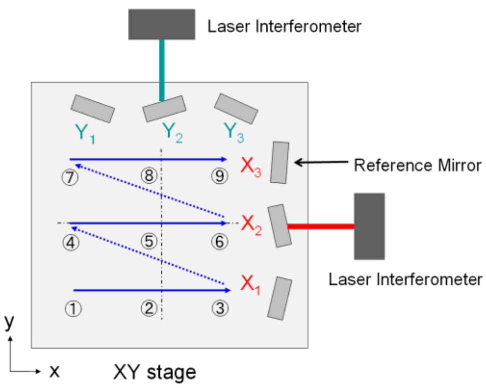


Fig. 9 Global stage moving process

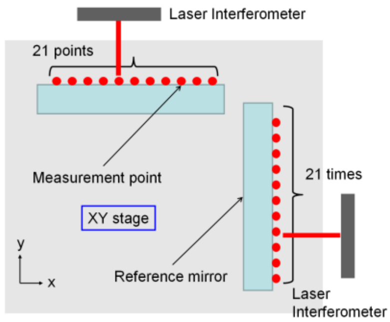
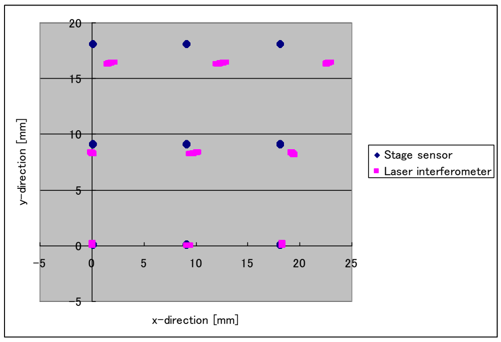


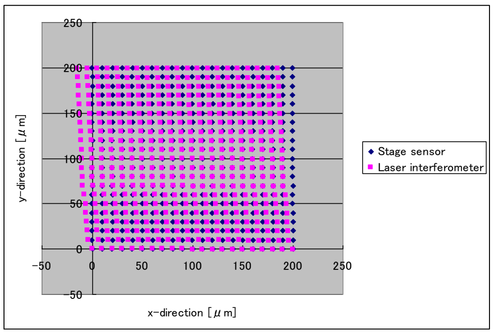
Fig. 10 Detail of each block ①～⑨

4.3 Experiment result

Fig. 11 shows measurement result by the sensors in the XY-stage and the laser interferometers.



(a) All measurement result



(b) Detail of block ① (Fig. 9)

Fig. 11 Experiment result

5. Calculated result

We estimated the axis shape of XY-stage and mirror profile of the reference mirrors by Least Square Method (LSM).

5.1 Axis shape

Fig. 12 shows calculated result of axis shape in x- and y-direction.

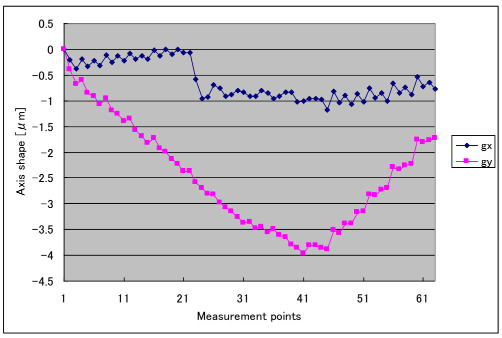
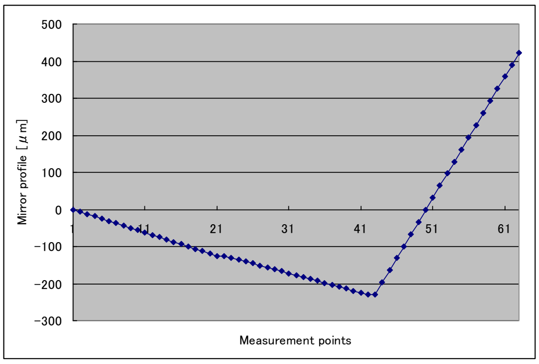


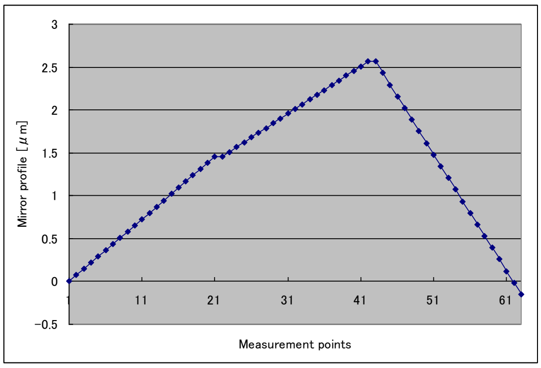
Fig. 12 Axis shape

5.2 Mirror profile

Fig. 13 shows calculated result of mirror profile in each direction of axis.



(a) gx



(b) gy

Fig. 13 Mirror profile

6. Consideration

From Fig. 12, PV of Fx is 1.2 [μm] and that of Fy is 4.0 [μm]. In this study, we use similar one-dimensional stages. So, this value must be almost same.

From Fig. 13, both gx and gy have three different slopes, so this method can estimate slopes of the reference mirrors. On the other hands, the maximum slope of the reference mirror of gx is 652 [μm] and that of gy is 2.7 [μm]. From Fig.11, almost measuring results of the laser interferometer in x-direction deviated toward the negative from that of stage sensors. As a result, this deviation was absorbed into the mirror slope.

From the above, it is not enough for this principle to separate the parameters from the measuring result. We should make new principle and simulations of the measurement result that don't have the deviation in x- and y-direction.

7. Conclusion

In this study, we tried to separate axis shape and mirror profile errors from measurement value of the laser interferometer. The conclusions are summarized as follows:

- We estimated parameters of axis shape and mirror profile by using LSM. Then we put gx and gy into primary funct ion. It is not enough to be separated from measurement va lue by this method.
- It is necessary to make new principle which separates erro rs from the measurement value.
- It is necessary to make simulations assumed not to deviate measurement value in x- and y- direction.

REFERENCES

1. Dongmin Kim, Dong Yeon Lee, Dae Gab Gweon Jeong Seok Oh, Eun Deok Bae, Taeho Keem, Seung-Woo, "A new nano-accuracy AFM system for minimizing Abbe errors and the evaluation of its measuring uncertainty," Ultramicroscopy 107, pp322–328, 2007
2. Jeong Seok Oh, Eun Deok Bae, Taeho Keem, Seung-Woo, "Measuring and compensating for 5-DOF parasitic motion errors in translation stages using Twyman–Green interferometry," International Journal of Machine Tools & Manufacture 46, pp1748–1752, 2006
3. Ryoshu Furutani, Masakazu Watanabe, "Measurement of Straightness for Two-Dimentional Translatry Stage" Key Engneering Materials, vol. 437, pp.194-197, 2010.