

THE ESTIMATION FOR ERRORS OF A PLANAR XY STAGE FROM PROFILES MEASUREMENT OF GUIDE-WAYS

Jooho Hwang¹, Chun-Hong Park¹, and Seung-Woo Kim²

¹Intelligent Machine Research Center, Korea Institute of Machinery and Materials, Daejeon, Korea

²Department of Mechanical Engineering, Korea Advanced Institute of Science and Technology, Daejeon, Korea

INTRODUCTION

A planar XY stage is frequently used as a precision positioning system for equipment producing semiconductors or flat panel display. Therefore, higher velocities and better accuracies are required to reach higher productivity and performance measures. A planar XY stage, for which an H-shaped frame is usually used as a base stage, is driven by two actuators, such as linear motors, with two position feedback sensors, such as linear scales or interferometers on the scanning motion axis. The stage is frequently used as main frame of the equipment. Therefore the machining and assembly process of rail and bed of the stage is one of first process during the equipment is built. The 2D position error, motion error and flatness of the stage can be measured when the real test is performed. If the errors of stage didn't meet the requirement of it's specification, the stage must be corrected for machining and assembly process again. It is difficult and time consuming work, if assemble and disassemble process is repeated for such a big stage.

In this paper, the estimation method for errors of a planar XY stage is suggested, which is applied during the rails and bed of stage is evaluated. To estimate the errors of a planar XY stage, profiles measurement, estimation of motion error and 2D position estimation model is used.

As shown in Figure 1, the moving table of a planar XY stage is translated along the X-axis on the base stage, which has an H-type structure and is driven by two simultaneously controlled linear motors (LM310-4, Trilogy) along the Y-axis. The stroke of each axis is 300 mm, which can be measured using a precise optical linear scale (LIP481, HeidenHain). A PC-based motion control board with a PID filter (PMAC2, Delta Tau) is used to control the position of the stage. The X and Y axes move on a granite bed, which is used as a vertical guide of vacuum preloaded aerostatic bearings for two stages to avoid deflection of the table and base stage and to reduce the moment force in high acceleration motions. A double pad aerostatic bearing is used to constrain horizontal motion. As shown in Fig. 1, the base stage is constrained against horizontal motion only at the aerostatic bearing on the Y_1 -axis.

PROFILE MEASUREMENT OF GUIDE-WAYS

The profile of guide way is measured by three-probe system, that can be used to measure the parallelism and straightness of a pair of rails simultaneously [1]. The parallelism is measured using a modified reversal method, while the straightness is measured using a sequential two-point method as shown in Figure 1. The profile can be expressed as

CONFIGURATION OF PLANAR XY STAGE

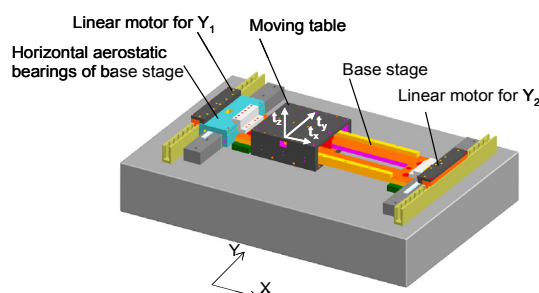


Figure 1: Schematic diagram of a planar XY stage

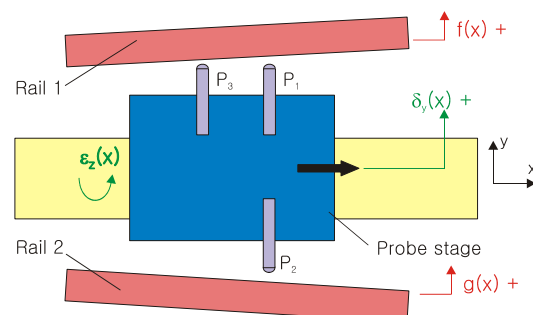


Figure 2: Setup for measuring parallelism and straightness

$$\begin{aligned} f(x_i) &\approx f_d(x_i) = f_d(x_{i-1}) + m_1(x_i) - m_3(x_i) + l\varepsilon_z(x_i) \\ g_d(x_i) &\approx f_d(x_i) - (m_1(x_i) + m_2(x_i)) \end{aligned} \quad (1)$$

Where, $m_1(x)$, $m_2(x)$ and $m_3(x)$ are measured data of corresponding probes. The measured profiles of each guide-ways are shown in Figure 1~3.

ESTIMATION OF THE MOTION ERROR

Static equilibrium model of stage

The static equilibrium modeling, which is considered by change of reaction force and displacement for single porous pad of aerostatic stage, is shown in Fig. 6. Where, W is external load of table including weight; m is number of the pad in table; X_{ci} is distance from center of

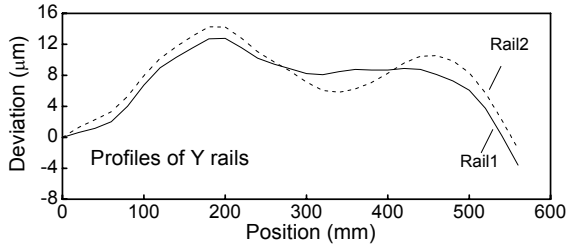


Figure 3: The profiles of Y axis rails

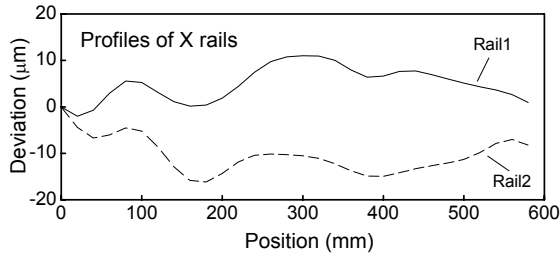


Figure 4: The profiles of X axis rails

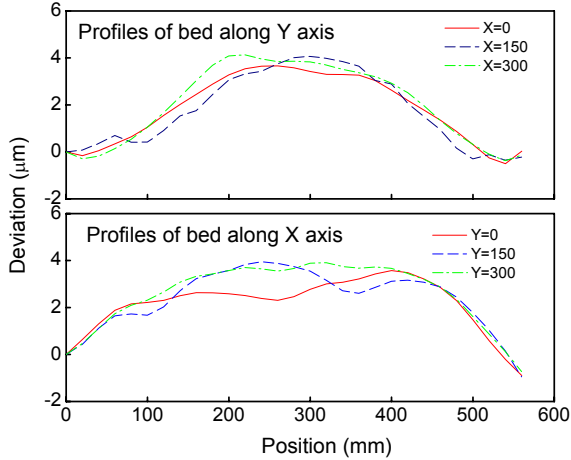


Figure 5: The measured profile of bed along X and Y axis

table to center of pads; L is length of rails; $F_i(x)$ and $Z_i(x)$ are i^{th} reaction force and corresponding displacement of center of pads, while position of center of table is x ; $\theta(x)$ is slope of the table.

If the relationship between the profile of rails and each pads of table is considered, the pad of table is moved to new equilibrium state owing to changed aerostatic reaction force ($f_{ei}(x)$) and new displacement of stage ($z_i(x)$), while the reaction force is $F_i(x)$.

Assuming the stiffness of aerostatic pads are constant within the small displacement of stage, the relationship between the $f_{ei}(x)$ and $z_i(x)$ is explained as

$$f_i(x) = f_{ei}(x) - K_0 z_i(x) \quad (2)$$

Considering the Eq. (2), moment equilibrium from reaction force of pads is explained as Eqs. (3) and (4).

$$\sum_{i=1}^m \{f_{ei}(x) - K_0 z_i(x)\} = 0 \quad (3)$$

$$\sum_{i=1}^m f_{ei}(x) \left(X_{ci} - R_i(x) + \frac{ml}{2} \right) = \sum_{i=1}^m K_0 z_i(x) \left(X_{ci} + \frac{ml}{2} \right) \quad (4)$$

$$x = \frac{ml}{2}, \dots, L - \frac{ml}{2}$$

The Fourier transformed profiles of rails ($e(x)$) is explained as

$$e(x) = a_0 + \sum_{k=1}^n \left(a_k \cos \frac{2k\pi}{L} x + b_k \sin \frac{2k\pi}{L} x \right) \quad (5)$$

Computation of motion error

The aerostatic bearing pads of the stage are same shape and multi supported configuration in same plane, as shown in Figure 6. Therefore, the error motion of the moving table of the stage can be calculated, from geometric relationship of each pads and calculated characteristic of one pad. It has advantage of fast calculation time during assembly process of the stage.

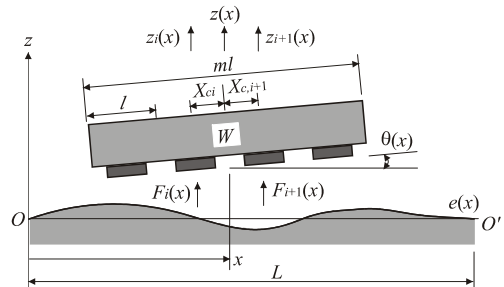


Figure 6: Equilibrium state of a porous aerostatic stage

When a porous pad is moving along the rails and the center of pad has same coordination with rails, the profiles of rails in Eq.(5) and change of reaction force of a porous pad($f_e(x)$) can be explained as spatial frequency(ω). The spatial frequency is defined as $\omega=2\pi/\lambda$, where, the wavelength for one of the sinusoidal profiles of rails is defined as λ . And, in the case of wave length is as same as length of pad (l), the spatial frequency is defined as $\omega_1=2\pi/l$. The change of reaction force($f_e(x)$) has same spatial frequency with rails, if the profile of rail, which has profile $e(x)$ with only single spatial frequency ω . From this relationships, the motion transfer function will be defined as

$$K(\omega) = \frac{f_e(\omega)}{e(\omega)} \quad (6)$$

linear motion error and angular motion error may be represented by

$$z(x) = \frac{1}{K_0 m} \sum_{i=1}^m f_e(x + X_{ci}) \quad (7)$$

$$\theta(x) = \frac{12}{K_0 m(m^2 - 1)^2} \sum_{i=1}^m \{f_e(x + X_{ci})(X_{ci} - R_i(x + X_{ci}))\}$$

Where, the $f_e(x)$ and $R(x)$ can be represented by Eq.(8) and Eq.(9)[2].

$$f_e(x) = \sum_{k=1}^n K \left(\frac{2k\pi}{L} \right) \left(a_k \cos \frac{2k\pi}{L} x + b_k \sin \frac{2k\pi}{L} x \right) \quad (8)$$

$$R(x) = l \sum_{k=1}^n G \left(\frac{2k\pi}{L} \right) \left(a_k \cos \frac{2k\pi}{L} x + b_k \sin \frac{2k\pi}{L} x \right) \quad (9)$$

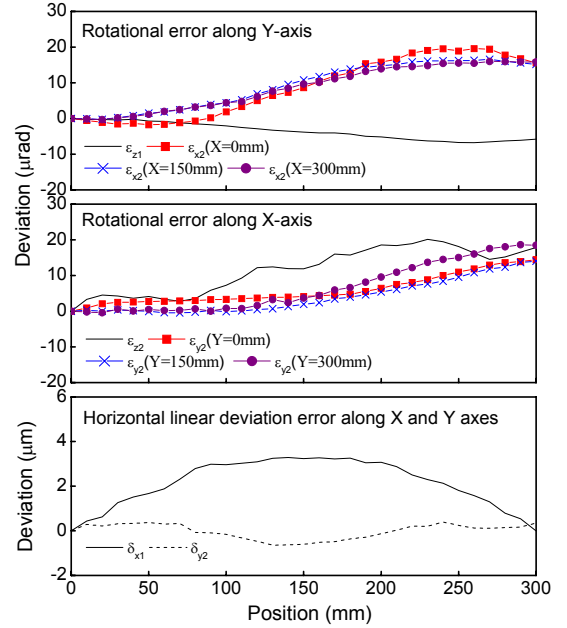
The motion errors of stage can be acquired by sequential repetition calculation along moving directions.

THE ESTIMATION OF 2D POSITION AND FLATNESS ERRORS FROM THE MOTION ERRORS

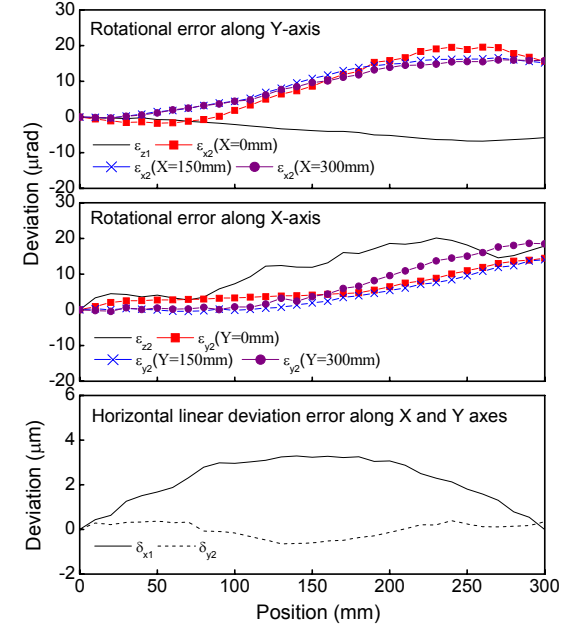
The 2D position errors estimation model of planar XY stage was introduced about same stage, it is represented by Eq. (10)[3].

$$\begin{bmatrix} \delta P_x(i, j) \\ \delta P_y(i, j) \end{bmatrix} = \begin{bmatrix} -t_x(\varepsilon_{z1}(j) + \varepsilon_{z2}(i)) + t_z \varepsilon_{y2}(i, j) + \delta x_1(j) + \delta x_2(i) \\ t_x(\varepsilon_{z1}(j) + \varepsilon_{z2}(i)) - t_z \varepsilon_{x2}(i, j) + a_2(i) \varepsilon_{z1}(j) + a_2(i) \theta_{12} + \delta y_1(j) + \delta y_2(i) \end{bmatrix} \quad (10)$$

In Eq. (13), each error motion contains an i or j index, or both. These are intermittent steps of the estimation and measurement process of the 2D error in the X and Y directions, respectively. The motion errors of the stage were compared in Figure 7, between measured by inter-



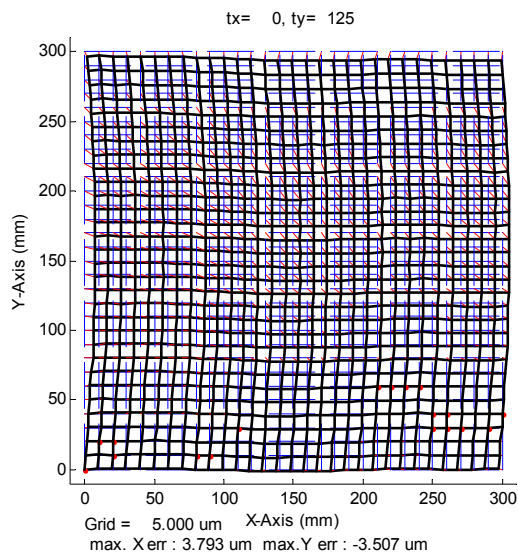
(a) Measured motion errors



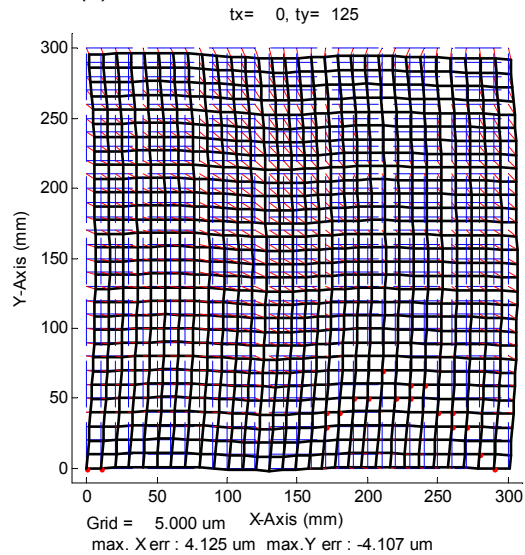
(b) Estimated motion errors

Figure 7: Comparison between measured and estimated motion errors of the planar XY stage

ferometer and estimated motion error using Eq. (7) and the results of Fig. 3~5. The yaw motion of base stage (ε_{z1}) is affected by controlled position of each of y_1 and y_2 axis. Therefore, measured data of ε_{z1} was used in estimation of 2D position both of the cases. As shown in Fig. 7, the most of motion errors are similar, but yaw motion of moving table along X axis was shown in little bit different shape.



(a) From measured motion errors

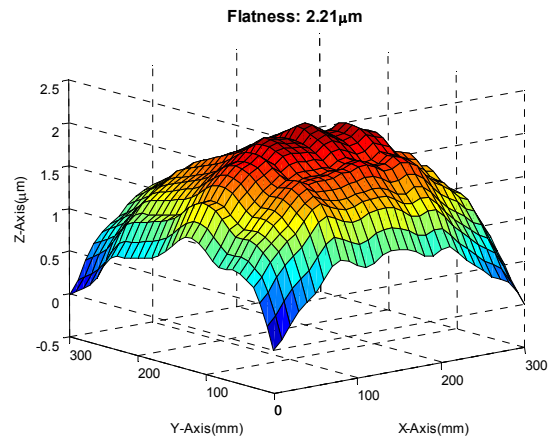


(b) From estimated motion errors

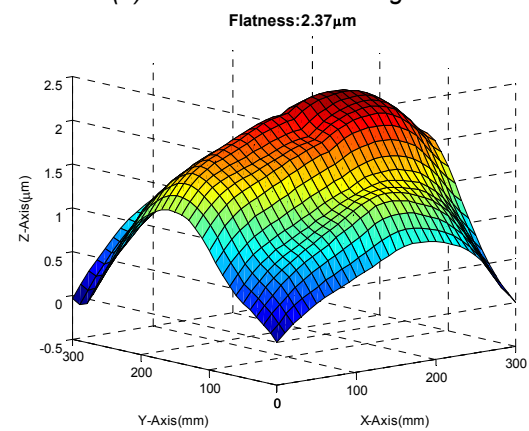
Figure 8: Comparison of 2D position errors of the planar XY stage at the center

The 2D position error of the stage was estimated from the sum of the motion errors every 10 mm over the 300 × 300-mm translational area. The 2D position errors were compared in Figure 8 for $t_x = 0$ mm, $t_y = 125$ mm, $t_z = 60$ mm, and $\theta_{12} = 0$. Interpolation was used to estimate the pitch errors $\varepsilon_{x2}(i,j)$ and $\varepsilon_{y2}(i,j)$, which had similar shapes at the three different measured positions because the position difference of 150 mm was less than the span of the aerostatic bearings of the moving table (270 mm).

The straightness of flatness can be simply calculated from summation of each interpolated



(a) From measured straightness



(b) From estimated straightness

Figure 9: The comparison between measured and estimated flatness

straightness data which can be measured directly or estimated from measured profile data. The comparison of flatness data were shown in Fig. 9. As shown in Fig. 9, the flatness also can be estimated from measured profile of surface of granite bed.

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