Proceedings of the World Congress on Engineering 2008 Vol II
WCE 2008, July 2 - 4, 2008, London, U.K.

Positional Accuracy of an Alignment Stage for a Large-area UV Nanoimprint Lithography

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Abstract— **Positional accuracy of an alignment stage for a large-area UV Nanoimprint lithography (UV-NIL) is evaluated. This paper describes accuracy measurement of a high precision stage for UV-NIL applications. In UV-NIL, an alignment stage is essential since the accuracy of the pattern transfer depends only on the positional accuracy of the stage. We measured the accuracy of an alignment stage when the viscous resin was filled between the mold and the glass panel. The positional accuracy without any resin was also measured for comparison. We used a laser interferometer system to measure the position of the stage in the X and Y axis. A simulation is also carried out by using a FEM package ALGOR, and the positioning errors by deformation of the components are calculated. The comparisons and the results are discussed.**

Index Terms—**Alignment stage, Kinematics analysis, Positional accuracy, UV nanoimprint lithography.**

I. Introduction

A planar stage with three degrees of freedom is widely used for an alignment process in various applications, which include MEMS, semiconductor wafers, and LCD inspection. In the alignment process, the role of the stage is essential since positioning accuracy of the patterns to be transferred by the alignment process sorely depends on the accuracy of the stage. Thus, the positioning capability of the stage is required to be more and more accurate. Submicrometer positioning accuracy can be possible for the alignment with commercially available stages [1].

For a pattern transferring process of UV nanoimprint lithography (UV-NIL), the alignment stage is also essential. Recently, the UV-NIL is suggested as an alternative lithography process to the photo- lithography process. The UV-NIL process is composed of several processes, which is depicted in Fig. 1. As the first procedure, low-viscoelastic resin is coated on the target-panel as a patterning material in order to transfer the nanopatterns or micropatterns inscribed on the mold into the target panels. Then, an alignment between the mold and the target panel is processed. During the alignment process, the fiducial marks on the mold and the glass-panel have to be coincided in order to ensure the position of the nanopatterns on the proper position of the target panel. The alignment marks are depicted in Fig. 2. Then, a curing process follows, where the liquid resin is solidified by UV light and forms the patterns.

The accuracy and repeatability of the stage is the most important feature when the UV-NIL process is applied to large area LCD manufacturing. The stage aligns the mold patterns and the target glass patterns with respect to the fiducial marks, after a viscous resin is laminated between the mold and the target panel. Thus, the viscosity of the resin can induce a shear force on the stage, and the force would make positional error in alignment process. The measurement of the accuracy and repeatability of alignment stages is a typical process for the inspection after the manufacturing [2]. However, the positional accuracy during the alignment process in the viscous friction condition should also be checked for the enhancement of the alignment process and an evaluation of the stage.

In this work, we measured the positional accuracy for an alignment stage system, where the shear force from the viscous resin is induced during the alignment process. The stage is developed as an alignment system for a UV-NIL process for a large area LCD manufacturing. We discussed the difference of positional errors between with the viscous resin and without the resin.

This paper is organized as follows: In section 2, the structural details of the alignment stage is presented. Kinematics analysis for the stage is also evaluated for understanding of the stage actuation. In section 3, the experimental details are presented. We present the experimental set-up, the result of experiments, and discussion for the positional error. In section 4, a FEM simulation is presented in order to analyze the position error of the stage. The concluding remarks follow in Section 5..

II. The Structure of an Alignment stage

A. *Components of the alignment stage.*

A typical schematic diagram of a planar stage with three degrees of freedom is depicted in Fig. 3, which stage is manufactured by the Hephaist Seiko Company [1]. Three ball-screw systems actuate the stage, which ball-screws are driven by servo-motors. The ball-screw systems change a rotational motion of the servo-motors into a linear motion. Each ball-screw system is connected to a slider part in front

Manuscript received March 22, 2008. This work was supported by Seoul Research & Business Development Program (Grant No.10583) and by the Korea Research Foundation Grant funded by the Korean Government (MOEHRD) (KRF-2007-331-D00015)

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of a fixture bracket [3]. The slider part moves a cross-roller bearing part, which operates as a joint component with two degrees of freedom. The cross-roller bearing part is fixed to the upper plate of the stage. A rotary encoder integrated in the servo-motor is used to read the position of each actuator. With three actuators, the alignment stage operates three degrees of freedom motion: two translations in the X and the Y direction and one rotation along the Z axis, i.e the θ-direction. The specification of the alignment stage is proposed in Table I.

B. Kinematic analysis

The kinematic diagram for the alignment stage is presented in Fig. 5. Each position of the actuators with the ball-screw systems is represented as P_{f1}, P_{f2}, and P_{f3}, respectively. The actuators at P_{f2} and P_{f3} move the stage in the Y direction, and P_{f1} moves in the X direction. In the case of rotational motion of upper plate, the θ direction, the P_{f1}, P_{f2}, and P_{f3} move together at the same time [4].

Inverse kinematics analysis is to calculate the positional value for each actuator by using the position and orientation of the stage. The input value for each actuator is described as q_1, q_2 and q_3, and the position and orientation of the center of the stage is defined as Δx, Δy, $\Delta\theta$. If the stage moves to a target position P'_m from initial position P_f, the kinematic equation of the stage system can be written as follows,

$$\begin{bmatrix} P'_{mx} \\ P'_{my} \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} P_{fx} \\ P_{fy} \end{bmatrix} + \begin{bmatrix} \Delta x \\ \Delta y \end{bmatrix} \tag{1}$$

We can write down the position of the actuating points as (2). The points are located on the edges of the stage and are depicted as P'_{m1}, P'_{m2}, P'_{m3}, P'_{m4} in Fig. 5.

$$\begin{aligned} P'_{m1} &= \begin{bmatrix} P'_{m1x} \\ P'_{m1y} \end{bmatrix} = \begin{bmatrix} -400\cos\theta - 400\sin\theta + \Delta x \\ -400\sin\theta + 400\cos\theta + \Delta y \end{bmatrix}, \\ P'_{m2} &= \begin{bmatrix} P'_{m2x} \\ P'_{m2y} \end{bmatrix} = \begin{bmatrix} -400\sin\theta + \Delta x \\ 400\cos\theta + \Delta y \end{bmatrix}, \\ P'_{m3} &= \begin{bmatrix} P'_{m3x} \\ P'_{m3y} \end{bmatrix} = \begin{bmatrix} -400\cos\theta + \Delta x \\ -400\cos\theta + \Delta y \end{bmatrix}, \\ P'_{mc} &= \begin{bmatrix} P'_{mcx} \\ P'_{mcy} \end{bmatrix} = \begin{bmatrix} \Delta x \\ \Delta y \end{bmatrix}, \end{aligned} \tag{2}$$

The command values for the actuators can be calculated from the following equation.

$$\begin{aligned} P''_{m1y} &= 400 + q_1 \\ P''_{m2x} &= q_2 \\ P''_{m3x} &= -400 + q_3 \end{aligned} \tag{3}$$

$$\begin{aligned} q_1 &= -400\sin\theta + 400\cos\theta + \Delta y - 400 \\ q_2 &= -400\sin\theta + \Delta x \\ q_3 &= -400\cos\theta + \Delta x + 400 \end{aligned} \tag{4}$$

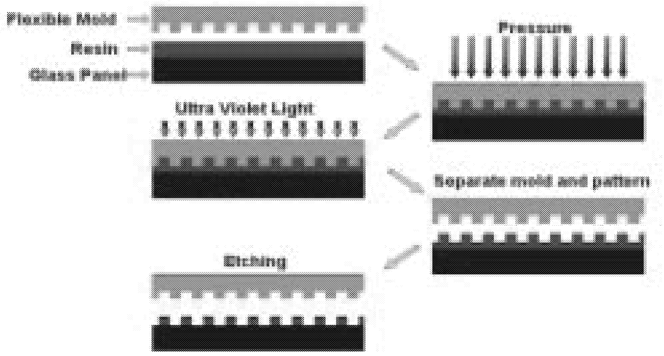

Fig. 1 Processes of a UV nanoimprint lithography

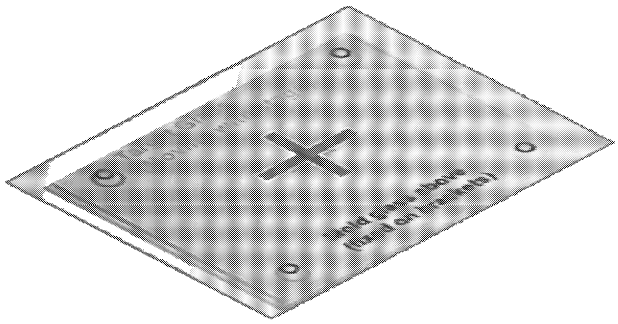

Fig. 2 Fiducial marks in an alignment process

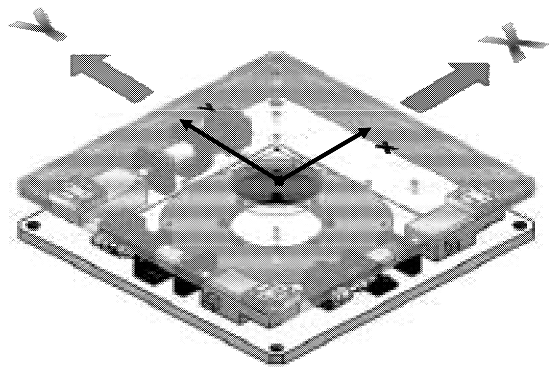

Fig. 3 Structural details of a 3-d.o.f. alignment stage

TABLE I SPECIFICATION OF THE ALIGNMENT STAGE

stage size	L	400mm
stroke	S	Within ±10mm
rotation	Θ	Within ±2.5°

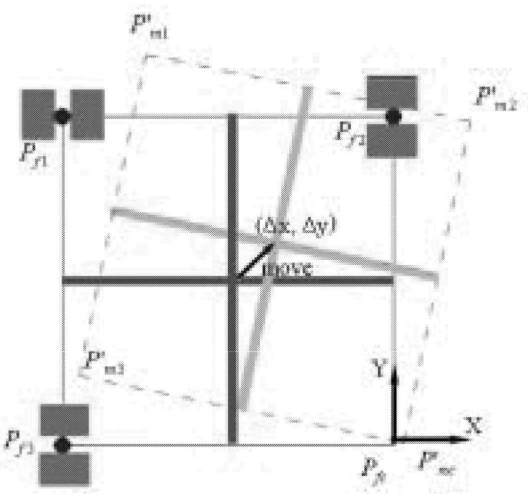

Fig. 4 Kinematic configuration of joints of the stage

ISBN:978-988-17012-3-7

Forward kinematics is to calculate the position and orientation of the stage by using the command values of actuators [4]. The forward kinematics of the alignment stage can be written as the following equations:

$$\Delta x = q_2 + 400\sin\theta$$

$$\Delta y = q_1 + 400\sin\theta - 400\cos\theta + 400$$

$$\Delta\theta = \sin^{-1}\frac{\left[1-\left(\frac{q_2 - q_3 + 400}{-400}\right)^2\right]}{2}$$

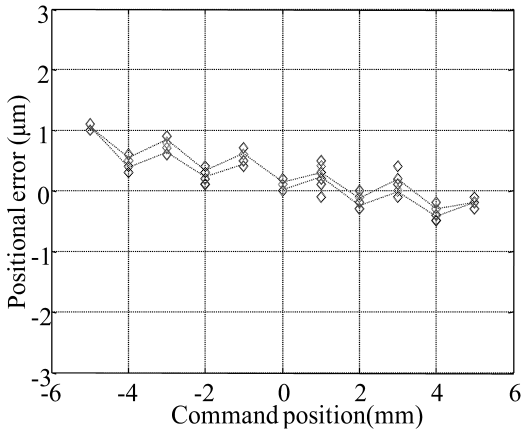

Fig. 8 Positional error of the alignment stage in the X axis

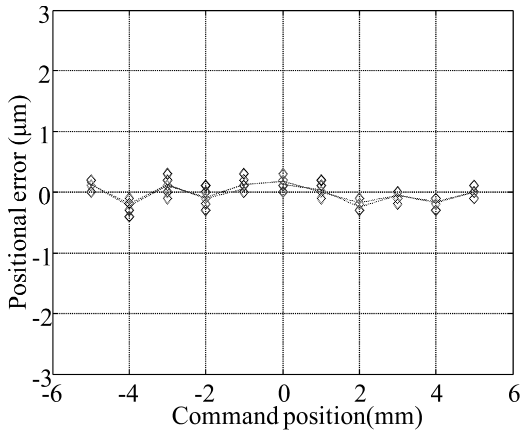

Fig. 9 Positional error of the alignment stage in the Y axis

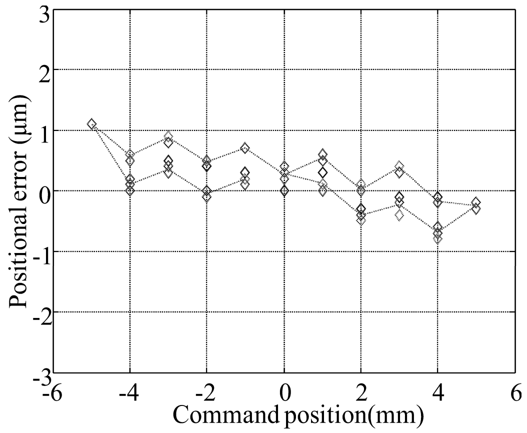

Fig. 10 The positional error in the X axis with the UV viscous resin

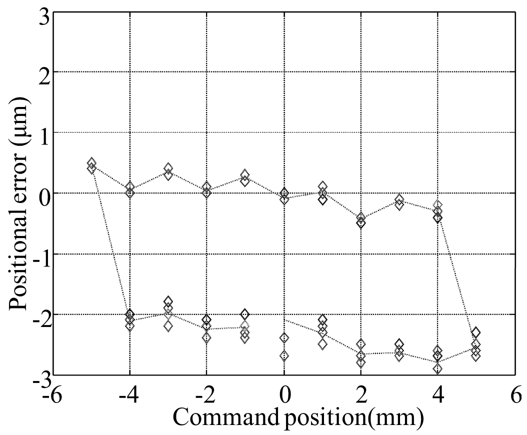

Fig. 11 The positional error in the Y axis with the UV viscous resin

The second experiment was executed when a UV resin was laminated between the mold and the panel as shown in Fig. 7. The resin is usually treated as viscous-elastic and isotropic material. The viscosity of the resin can induce the shear force on the glass-panel as well as the alignment stage. Thus, the positional accuracy of the stage for aligning the mold and the glass-panel with the resin should be evaluated in order to ensure the alignment process. The detail properties of the UV resin is presented in Table III.

The experimental results in the X axis and in the Y axis with the viscous resin are depicted in Fig. 10 and Fig. 11, respectively. The backlash by the shear force due to the viscous resin is observed in both experiments. In the case of the X axis, the range of the positional error was from -0.8μm to 1.1μm, and the maximum backlash value was 0.8μm at the 3mm position. The total range of the positional error was not changed much but was similar to the case without the UV resin. In the case of the Y axis, however, the positional error measured was dramatically changed; a large backlash, around 2μm was observed. Moreover, the accuracy of the Y axis positioning was over 3.5μm, which exceeded the design specification of the stage [1].

When there was no resin on the glass-panel, the positional accuracy of the Y axis was better value than the accuracy of the X axis. However, the measurement of the positional accuracy with the resin showed different behavior. The different behavior for the positional accuracy came from the structural unbalance to react against the shear force. The stage installed two ball-screw actuators for the directional motion in the X axis.

These two actuating ball-screw system were equally spaced with respect to the area covered by the resin. In the case of the Y axis motion, only one ball-screw system received the shear force. Since the ball-screw actuator was installed only one side of the stage, the shear force could induce a moment couple on the upper plate of the stage. That is, the unbalancing force induced an orientational error, and amplified the positional error on the Y axis.

The alternative design to eliminate the unbalanced interaction is to add a ball-screw system on the other side of the stage. By adding an additional axis, the shear force from the resin and the reaction force from the ball-screw will be balanced each other, and the orientational error can be reduced [8]. However, the additional actuator will impose force redundancy on the stage. The force redundancy can cause internal force on the stage system, and may make physical damage on the components of the stage. In the case that a mechanism has more actuators than the degrees of freedom, the mechanism is called as a redundantly actuated mechanism. Thus, a calibration procedure and a control algorithm that can prevent the internal force are essential for the development of redundantly actuated 4 axis stages.

IV. FEM ANALYSIS

From the experimental results, we observed that the positional error in the Y axis was more severe than the positional error in the X axis. This phenomenon came from the unbalance in installing the ball-screw system. We simulated the static displacement of the stage when the shear force due to the viscous resin was induced on the upper surface of stage. We used a FEM software package, ALGOR for the simulation.

We built a simplified model for modeling the stage. The each ball-screw was modeled as a spring and beam elements. The cross-roller bearing was modeled as two slider elements. Line elements were used for modeling sliding parts and rotation parts, and the other details were ignored. Three pairs of the ball-screw systems were attached the bottom side of the upper plate of the stage. Then, distributed forces in the X direction and in the Y direction was induced on upper plate, respectively. The displacements by the distributed forces were calculated. A result of the simulation was depicted in Fig. 12.

In the case of the X axis force, the displacement in the same direction was observed. However, the simulation results showed that the stage was rotated by the shear force in the Y direction. Even though the distributed force was imposed on whole surface of the stage, the unbalance of the ball-screw installation made a rotational displacement of the stage. The rotational displacement of the stage should be eliminated because the rotational error may amplify the positional error with respect to the curvature from instantaneous center. This simulation results matched the experimental results. The balance of the reaction force should be considered in designing process of the UV nanoimprint lithography.

V. CONCLUSION

In this research, an alignment stage for UV nanoimprint lithography was analyzed. The forward and inverse kinematics for the stage were analyzed and the solutions of kinematic problem were suggested. By using a laser interferometer system, the positional error in X axis and the Y axis were obtained in the cases of with the viscous resin and without the resin. The positional accuracy in the X axis was more robust than that of the Y axis. In the cases without the resin, the range of the positional error in X axis was ±1μm, and the unidirectional repeatability was ±0.469μm. The range of the positional error and the repeatability in the Y axis was ±0.5μm and ±0.316μm, respectively. In the cases with the viscous resin, the positional error in the X axis was from -0.8μm to 1.1μm, and the maximum backlash value was 0.8μm. In the case of the Y axis with the resin, the accuracy and the backlash were 3.5μm and 2.1μm, respectively.

As an alternative design, the four axis stage was suggested in order to balance the reaction force and to prevent the orientational error of the stage.

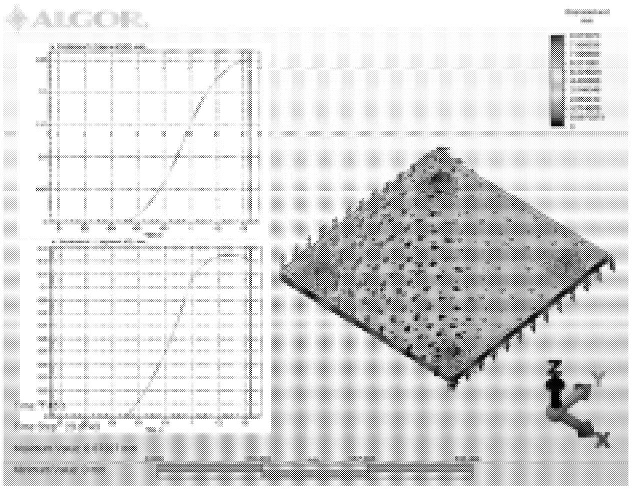

Fig. 12 Simulation of 3-axis stage (by ALGOR)

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