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# Multi-layer alignment control of a large area nano-imprinting stage [†]

Hong Jae Yim, Yong Hoon Lee, Sung Hoon Lee, Jay Il Jeong and Si-Hyung Lim*
*School of Mechanical and Automotive Engineering, Kookmin University, Seoul, 136-702, Korea*

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## Abstract

An XYθ stage for large area UV Nano-Imprinting Lithography (UV-NIL), which consists of linear actuators, translational/revolute joints, etc., has been modeled as flexible bodies. Multi-layer alignment control for the translation and angle offset cancellation has been performed in a virtual simulation environment using both ADAMS/Control and Matlab/SIMULINK. Furthermore, the vertical motions of three and four axis stages during the control action have been analyzed and compared to each other. The performed analysis can provide useful information for a high precision NIL stage development in the future.

*Keywords*: UV Nano-imprinting lithography; Stage; Multi-layer alignment control; Simulation

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## 1. Introduction

Recently, the nano-imprinting lithography (NIL) technique has been used for nano scale feature fabrication on a resist on top of the substrate layer. The display application area like LCD fabrication is one of the most promising application areas for the NIL technique [1]. Nowadays, a large area (eg. Display 2nd generation: 370×470 mm$^2$) imprint lithography has been tackled using thermal or ultra-violet(UV) curing method. Also, multi-layer NIL has been attempted in order to make multiple imprint layers. For this purpose, the alignment between the bottom and the top layers is very important and can be done using a high precision XYθ stage consisting of linear actuators, translational/revolute joints, etc. Lee et al. [2] demonstrated the wafer scale alignment control using an ultra precision stage in a conventional photo lithography process. Also, Shin [3] reported large area PCB alignment error correction for a screen printer using machine vision.

Many imprinting stages have been developed using three actuators, because three actuators are enough for x, y, θ operations and micrometer level stage motion. These imprinting stages could also be made with four actuators, but would cost more. However, it is questionable that the stage having only three actuators is sufficient enough for the overall NIL process. In this paper, a high precision stage for 370×470 mm$^2$ size UV-NIL was modeled as flexible bodies. Both translational and rotational control for misalignment correction was performed using machine vision. Furthermore, each vertical motion of the three and four axis stages was analyzed and compared to each other.

## 2. Modeling of a virtual nano-imprinting stage

Fig. 1 shows a UV-NIL machine used to make microscale patterns on a LCD glass panel (370×470 mm$^2$), which consists of a high precision motion stage, substrate glass panel and mold holders, and machine vision cameras (not shown in the figure). The high precision motion stage consists of a glass fixing plate, an absorption plate, a middle plate, an upper plate, a bearing, and linear actuators (motors, translators, and

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*Corresponding author. Tel.: +82 2 910 4672, Fax.: +82 2 910 4839
E-mail address: shlim@kookmin.ac.kr

rotors), which are modeled using the 3D CAD tool CATIA, as is shown in Fig. 2. This stage performs X and Y axis translational motion (± 1 μm accuracy), and Z axis rotational motion. Kinematically, the stage can have three or four motor sets to perform both the translational and rotational motion. The current stage has a three axis stage mechanism using three actuators, as is shown in Fig. 2. As is shown in Fig. 3, the other stage has a four axis stage mechanism using four actuators and was designed to check for possible performance enhancement over our current three axis stage. In addition, to carefully check the motion response in the X, Y, and Z axis directions of the precision motion stage, an upper plate, a bearing, translators and rotors are all FEM modeled as flexible bodies [4]. The stage can have X-axis and Y-axis translational motion, and Z-axis rotational motion using three or four linear actuators. Fig. 4 shows the operation principle of the three axis stages, which consist of three pairs of linear actuators, translational and revolute joints [5].

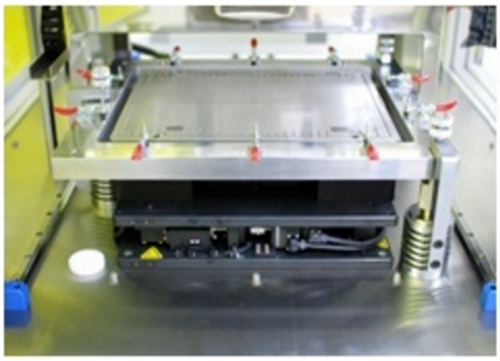

Fig. 1. Large area NIL stage having a three axis stage for LCD display application.

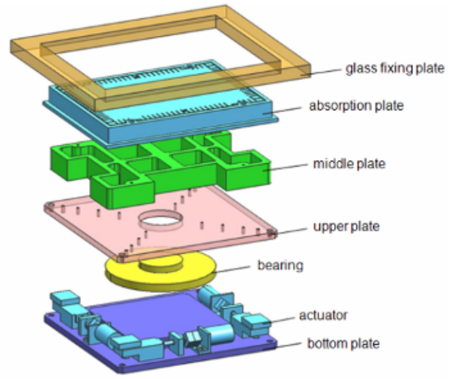

Fig. 2. 3D CAD Modeling of a nano-imprinting stage.

## 3. Multi-layer alignment control

The misalignment between the bottom and top layers should be calculated to perform an automatic alignment using vision cameras and the high precision XYθ stage explained above. For this purpose, the geometrical relationship between the cameras and the reference points of the layers should be considered [3]. A multi-layer alignment control simulation is performed using ADAMS/Control under the Matlab/SIMULINK environment. The ADAMS/Control has the dynamic flexible stage model explained in Sec. 2. As is shown in Fig. 5, it receives the control input torques for the three or four linear actuators and generates the measurement output variables of $\Delta x$, $\Delta y$, and $\Delta\theta$. The control input torques (torque 1~4 as shown in Fig. 3) are calculated by the control system to cancel the initial translational or rotational misalignment. Table 1 summarizes the number of input torques for making $\Delta x$, $\Delta y$, and $\Delta\theta_Z$ all equal zero in the three and four axis stages. In this paper, the initial misalignment values of $\Delta x = 5$ mm, $\Delta y = 3$ mm, and $\Delta\theta_Z = 1$ degree are arbitrarily fixed for control simulation, as is shown in Fig. 6.

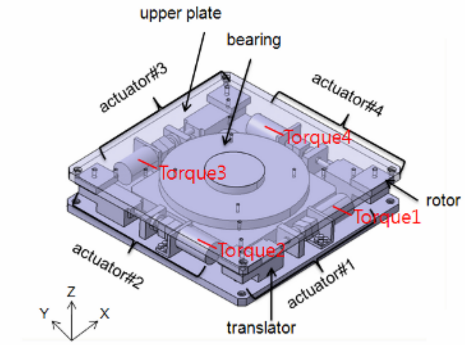

Fig. 3. Four axis stage mechanism.

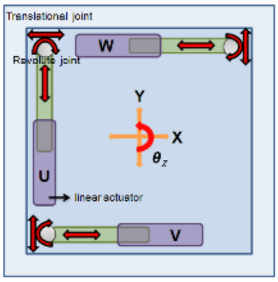

Fig. 4. Operation principle of the three axis stage.

Table 1. Relation between the input and output.

| Stage | Δx | Δy | Δθ |
|---|---|---|---|
| Three axis | Torque 1, 3 | Torque 2 | Torque 1~3 |
| Four axis | Torque 1, 3 | Torque 2, 4 | Torque 1~4 |

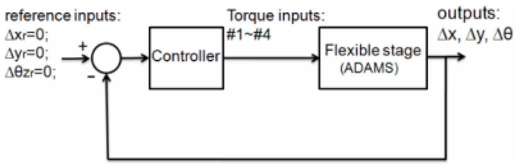

Fig. 5. Control system.

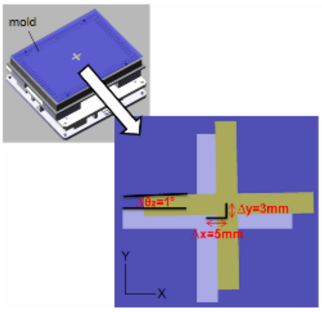

Fig. 6. Translational and rotational alignment control.

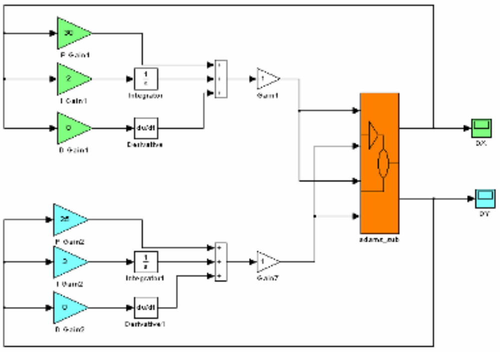

Fig. 7. SIMULINK block diagram for translational motion control in the four axis stage.

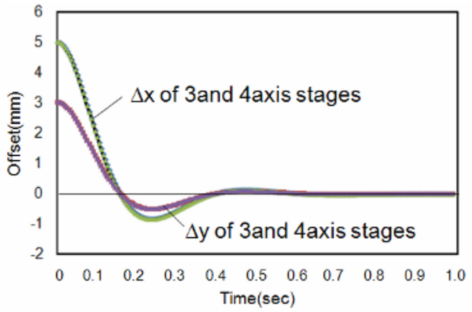

Fig. 8. Three axis and four axis translational motion control.

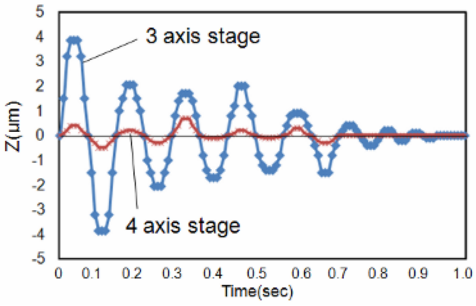

Fig. 9. Comparison of the Z-axis displacement during translational motion control.

The translational motion control was performed using a PID control algorithm to make the misalignment values equal to zero. Fig. 7 shows the SIMULINK block diagram for the translational motion control of the flexible stage model, the ADAMS/Control block. Fig. 8 shows the simulation results for the x-direction and y-direction control. After about 0.7 s, both translational offsets in the x and y directions converged to zero. On the other hand, the vertical displacement in the z direction was compared during the translational motion control. As is shown in Fig. 9, the absorption plate's vertical displacement at the CM (Center of Mass) marker in the case of the four axis stage was greatly reduced compared to that in the case of the three axis stage. The maximum vertical oscillation was reduced from 7.7 μm to 1.3 μm. The undesired large vertical oscillation in the three axis stage can cause defects in the patterned resist. Therefore, we must try to reduce the unwanted vertical oscillation of the upper plate. The increased vertical stiffness due to the additional linear actuator in the four axis stage can be the cause of the roughly 83% reduction in the maximum vertical oscillation. Therefore, the four axis stage is more robust during the translational offset cancellation control action. After the translational motion control, the rotational motion control was performed using a PID control algorithm. Fig. 10 shows the simulation results for three axis and four axis angle control. For the same PID gain, the four axis stage converges to zero 0.2 s faster than the three axis stage. Fig. 11 shows the absorption plate's vertical displacement at the CM marker during the rotational motion control. In a similar manner as in the translational motion control, the four axis stage shows much lower vertical oscillation during the rotational control action. The maximum vertical oscillation was

Table 2. Comparion of the maximum Z-axis oscillation during translational and rotational motion control.

| | Absorption plate's CM marker | |
|---|---|---|
| Control | Three axis stage | Four axis stage |
| Translation | 7.7 μm | 1.3 μm |
| Rotation | 7.9 μm | 0.7 μm |

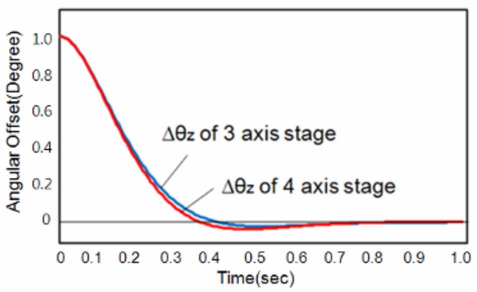

Fig. 10. Three axis & four axis angle control.

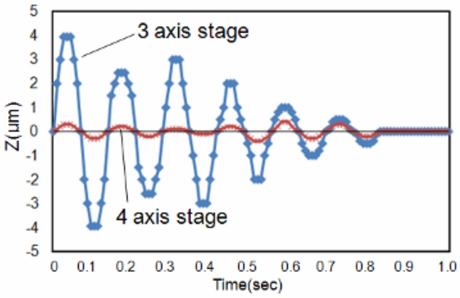

Fig. 11. Comparison of the Z-axis displacement during angle control.

reduced from 7.9 μm to 0.7 μm. Table 2 shows the maximum Z-axis oscillation.

## 4. Conclusion

An XYθ stage for a large area NIL was modeled as flexible bodies using both CATIA and ADAMS. Under a virtual simulation environment using both ADAMS/Control and Matlab/SIMULINK, the translation and angle offset cancellation control was performed for the automatic alignment. Furthermore, the vertical motion of the stage was analyzed for both the three and four axis stages and the undesired vertical motions during the control action were compared between the two types of stages. In the case of the four axis stage, the maximum vertical oscillations at the absorption plate's CM marker during the translational and rotational control actions had 83% and 91% reductions, respectively. The multi-layer alignment control work using ADAMS/Control having a virtual FEM stage model can be very useful in checking the stage behavior in the initial stage design for the NIL. In the future, a robust control algorithm and mechanism development for faster settling time and lower vertical oscillation will be investigated for the large area UV-NIL stage system.

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**Hong Jae Yim** received B.S. and M.S degrees in mechanical engineering from Seoul National University, Korea, in 1979, 1983. He received Ph.D degree from Univ. of Iowa, USA. He is currently a professor in School of Mechanical & Automotive Engineering, Kookmin University. His research interests are in the area of computer aided kinematics and dynamics of mechanical systems.