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Development of an Ultra Precise XY Motion Stage for Large Display Panel Manufacturing Equipment

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Abstract

We have developed an ultra precise XY motion stage for large display panel manufacturing equipment. It incorporates three challenging concepts to achieve nanometer-level positioning error over a long travel. The main features of the stage mechanism are as follows: 1) a coarse-fine mechanism to improve system dynamics and consequently enhance control bandwidth, 2) a reaction frame and isolation of a metrology frame to prevent the reaction forces caused by actuating motors from vibrating the metrology frame and optic system, 3) mass balancing which eliminates tilting and deformation of a base frame by maintaining the mass center of the stage system at the same position. In order to achieve nanometer precision, coreless linear motors and voice coil motors were used as actuators, and frictionless air bearings were used as motion guides. Also, differential type laser interferometers were used as position feedback making the fine stage follow a desired trajectory with respect to the optic system. We set up the stage system in an OLED fabrication facility, and evaluated its control performance. In-position stability and scanning error turned out to be less than 65 nm and 69 nm in 3 sigma, respectively. It was verified that the three key mechanisms implemented in the large stage system worked fine as designed, creating opportunities for broader applications with high level of size and precision requirements. Using the stage-equipped system, we are currently undergoing the pilot manufacturing process for OLED panels.

Keywords: Precision, Positioning, Motion, Mechanism

1. Introduction

Increasing demands for high-resolution displays due to population of high-end smartphones and head-mounted-display devices necessitate flat panel manufacturing equipment being capable of large-area traveling for high throughput as well as precise positioning for fine patterning. In dealing with these two contrasting requirements, dual stages each having a coarse and fine motion are considered highly effective since the coarse stage has a low bandwidth within a large travel range, while the fine stage has a high bandwidth within a small travel range [1]-[5]. This paper introduces an innovative coarse-fine stage system and presents its design, implementation and evaluation results. In addition, the stage system adopts two more precision means, metrology-frame isolation and mass balancing, for minimal deformation of its mechanical structure in dynamic conditions. Details of these two features will be also presented in this paper.

2. Design of the xy motion stage

The objective of our xy motion stage is to control the position of a glass substrate, sized 1500 mm x 1300mm, over a travel range of 560 mm and 2800 mm in x and y axes, respectively. In particular, it is crucial to maintain its position error less than 100 nm during multiple scan motions along y-direction at various x positions. It is also demanding requirement to place a moving mass, weighed about 4 tons, to a desired position quickly and accurately after a high speed motion with a velocity of 600 mm/s.

In order to meet these challenging specifications, the stage adopts three innovative mechanisms. First, the motion stage incorporates a coarse-fine concept. The coarse stage travels a long stroke with moderate precision, while the fine stage travels a short stroke with ultra precision. Figure 1 illustrates the concept of the proposed coarse-fine stage. The coarse stage is controlled in y axis using y_1- and y_2-linear motors under coarse y_1- and y_2-interferometer position feedbacks. The fine stage is controlled in x, y and yaw axes using a x-linear motor and y_1- and y_2-VCMs(voice coil motors) under fine x-, y_1- and y_2-laser interferometer position feedbacks. Both the coarse and fine stages are floated using frictionless air bearings to improve control performance. Since there is no mechanical coupling between the coarse and fine stage, external disturbance or mechanical resonance of the coarse stage does not affect the fine stage's positioning performance.

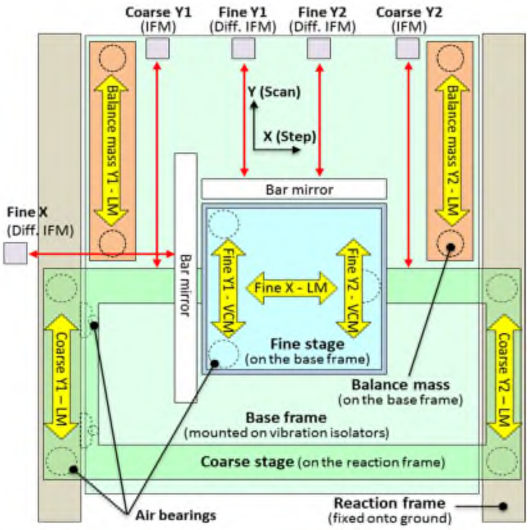

Figure 1. Schematics of the proposed stage; interferometers of the fine stage measure the relative distance between the fine stage and a metrology frame, which is shown in Figure 2.

Second, a reaction frame is implemented to prevent the actuating forces of motors from vibrating the metrology frame. Figure 2 shows mechanical structure of the stage system. The metrology frame, where the fine stage's feedback sensors are attached, is mounted on the base frame. The base frame is supported by vibration isolators which attenuate the vibration transferred from the floor. The reaction frame is separated from the base frame, and directly fixed onto the ground. The coarse stage's motors are installed on the reaction frame so that the reaction forces of motors are transmitted to the floor through the reaction frame instead of shaking the base and metrology frames. This design of isolating force disturbances makes the base and metrology frames silent, and improves the stage's stability and control bandwidth.

Finally, mass balancing is adopted to maintain the mass center of the stage system at the same position. Two balance masses are driven by each linear motor installed side-by-side on the reaction frame, and run in the opposite direction of the coarse-fine stage. This implementation minimizes deformation of the stage during the scanning motion by levelling base frame and stabilizing the metrology frame, and consequently improves accuracy and repeatability of the stage.

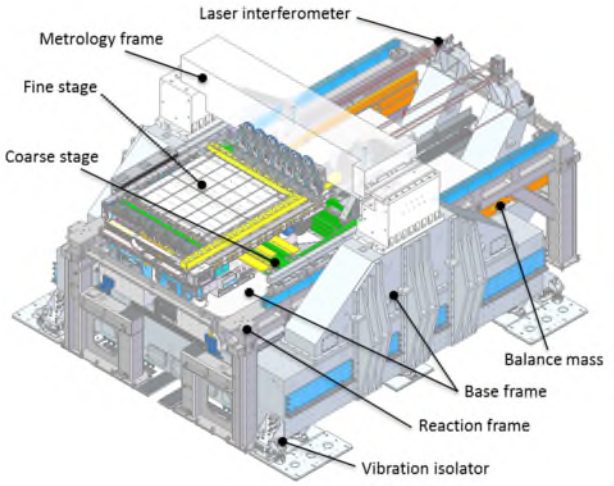

Figure 2. The detail structure of the developed XY motion stage

In more detail, the coarse stage is mainly composed of a main body, motor coils both for itself and fine stage. It weighs 1.8 tons. The fine stage consists of a ceramic body, a glass chuck, two bar mirrors, and motor magnet blocks. Its dimension is 1800 mm x 2800 mm x 900 mm and weight is 4.2 tons. As there is no motor coil being attached to the fine stage, but to the coarse stage, it is free from thermal deformation.

The position of the coarse stage is measured by laser interferometers which are installed on the base frame. The fine stage's position is measured by differential-type laser interferometers with respect to the metrology frame. As the optic system is mounted onto the metrology frame, the fine stage ends up precisely following the relative distance to the optic system.

The base frame incorporates welded steel structure for maximized natural frequency, and granite surfaces for precise air-bearing guides of the fine stage. Whole weight of the base and metrology frames is supported by six pneumatic passive isolators while floor vibrations are attenuated by four active isolators assembled at the four corners of the base frame.

The metrology frame is mounted onto the base frame, and flexure joints are implemented at the mounting areas for compensating the residual structure deformation and thermal deformation of the base frame. The overall dimension of the stage system is 4500 mm x 6500 mm x 3500 mm and its total weight is 72 tons.

3. Implementation and Performance Evaluation

The stage system was successfully installed in an OLED fabrication facility as a key module for the manufacturing equipment we developed. After setting up the hardware and electric control boxes, the coarse-fine control algorithm was implemented in the DeltaTau's PMAC controller with a 10 kHz sampling frequency. All linear motors were driven by linear amplifiers for enhanced positioning stability.

Its control performance is evaluated and presented in Figure 3, Figure 4 and Table 1. Two critical performance indices, in-position stability and position error during scan, found out to be less than 65 nm and 69 nm in 3 sigma, and meet the specifications.

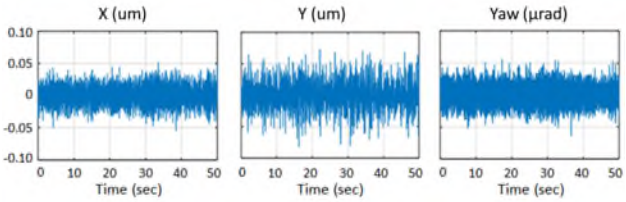

Figure 3. In-position stability at (x,y) = (280 mm, 1400 mm)

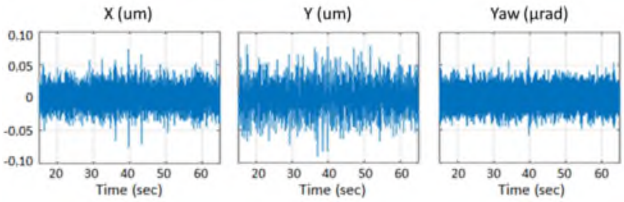

Figure 4. Position error during scan at X =280 mm; it was measured at a scanning velocity of 30 mm/s.

Table 1. Brief summary of control performance; scanning error and velocity ripple were measured at a scan velocity of 30 mm/s in y-axis.

Result	X (Step)	Y (Scan)	Yaw
Stroke	560 mm	2800 mm	±20 μrad
Max Velocity	500 mm/s	600 mm/s	N/A
Acceleration	0.05 G	0.1 G	N/A
In-pos. Stability	±0.040 μm	±0.065 μm	±0.042 μrad
Scanning Error	±0.046 μm	±0.069 μm	±0.048 μrad
Velocity Ripple	N/A	±0.039 %	N/A

4. Conclusion

We have developed a xy motion stage which is capable of nanometer-level positioning and handling of a large flat panel. Our stage design adopted several challenging concepts, i.e., coarse-fine mechanism, separation of force and metrology frames, and mass balancing. The stage was implemented in the equipment and installed in an OLED fabrication facility. Evaluation results showed that nanometer-level positioning was achieved over the large working area. Using the stage-equipped system, we are successfully undergoing the pilot manufacturing process for OLED panels.

5. References

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