A magnetically preloaded air bearing stage with 5-DOF motion error compensation

S.K. Ro[1], B.K. Lee[1], G. Khim[1], J.K. Park[1]
[1]*Korea Institute of Machinery and Materials, South Korea*
cniz@kimm.re.kr

Abstract

The aerostatic bearings are widely used for ultra-precision machines because of frictionless support and reduced motion errors especially for large range of precision movement such as semiconductor and flat panel display manufacturing system. The limit of motion errors occurs due to machining error of the guide surfaces, and there are many efforts for reducing the motion errors by active compensation or control. The active magnetic preload can be utilized for compensating motion errors.[1]

This paper introduces novel air bearing stage with 5-DOF active magnetic preloads. The proposed air bearing stage has magnetically preloaded with five magnetic actuators so that only two faces of the guide are used and 5-DOF motion, vertical and horizontal translations, pitch, yaw and roll motions, can be controlled actively in over 400 mm of travel range. The designed stage was manufactured and 5-DOF motion control gains were evaluated by measuring motions when control currents were applied to the five actuator coils. Motion errors of the stage were measured with combination of a multi-beam laser interferometer and capacitance sensors for two-point method. Finally the motion errors could be removed by feedforward method as level of measurement repeatability; for example, vertical straightness of 3.8 μm was reduced to 0.14 μm.

1. A linear air bearing stage with 5-DOF magnetic preloads

1.1 Design and manufacturing of air bearing stage

Figure 1 shows proposed 1-axis linear air bearing stage with five magnetic actuators for preloading and control of motions. Each magnetic actuator has permanent magnet for nominal preload and coil to adjust magnetic force. The air bearing pads are composed with porous material and designed based on numerical calculations. As the air bearings are preloaded by magnetic forces, only two guide way surfaces are required. Five magnetic actuators were located to generate vertical and horizontal

directional preloads, and combination of five forces can generate control force for generating 5-DOF motions. The magnetic actuators were designed to generate nominal preload of 160 N and control force of 38.4 N/A. Considering vertical stiffness of 120 N/μm, vertical motion can be expected about 0.65 μm/A by applying same current for actuator 1 and 2. The vertical stiffness of the air bearing table could be examined by simply measuring deformation with known weights, and it was measured as 130.8 N/μm at 0.3 MPa of supplied air pressure.

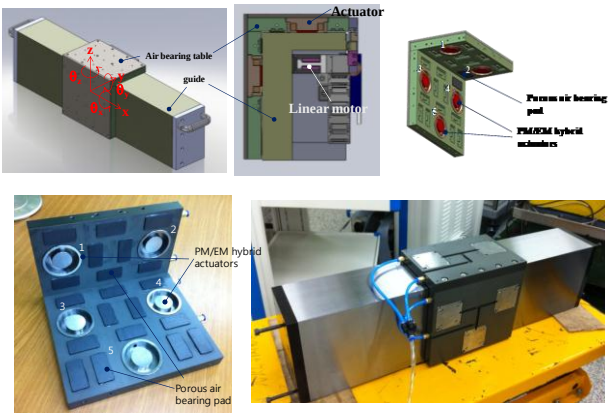

Figure 1: A linear air bearing stage with 5-DOF magnetic preloads

1.2 Control system and calibration of actuator gains

Control system for the stage is as shown in Figure 2. A PC-based controller (UMAC, Delta-Tau) was used for position and active preload control, and open loop preload control logic is in PLC program for running background of feedback loop of positioning control.

The relationship between table motions and input of actuators can be expresses as bellow simply,

$$\mathbf{y} = \mathbf{K}\mathbf{u}, \tag{1}$$

where $\mathbf{y}=[y, z, \theta_x, \theta_y, \theta_z]^T$ is the 5-DOF motion vector and $\mathbf{u}=[u_1, u_2, u_3, u_4, u_5]^T$ is input command vector of 5 actuators. The motion control gains, **K**, 5x5-matrix can be calculated from the actuator gains and measured by experiments. The compensation input **u** to compensate motion errors can be calculated directly from multiplying

inverse of the obtained gain matrix, $\mathbf{K}^{-1}$, to the 5-DOF motion errors. We measured the 25 elements of **K** by applying test input to each actuator with measurement set-up for 5-DOF motion errors.

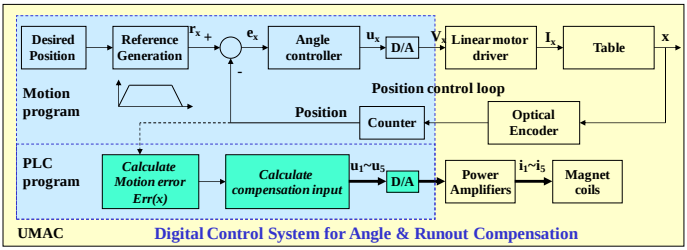

Figure 2: Control system for air bearing stage with 5-DOF active magnetic preloads

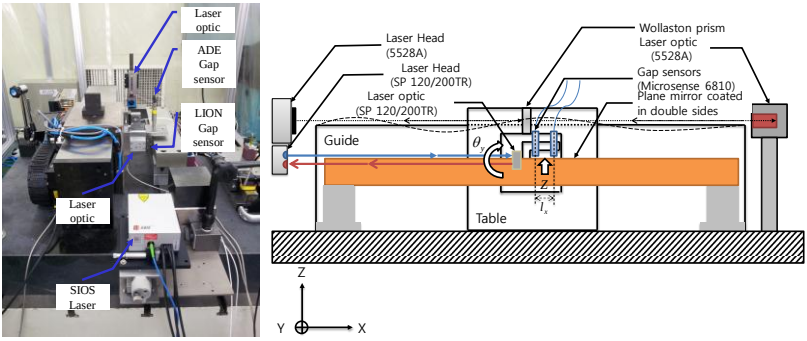

Figure 3: Measurement set up for 5-DOF motion errors

2. Measurement and active compensation of motion errors

Figure 3 shows the set-up for measuring 5-DOF motion errors. A laser interferometer with three beams measure position(x), pitch(θ_y) and yaw(θ_z) motions simultaneously. Vertical(z) and horizontal(y) straightness and roll motion(θ_x) are measured with four capacitance probes as two-point method using a dual side straight edge as reference. Figure 4 shows measured 5-DOF motion errors with and without active compensation. The all five errors were fitted as fourth order functions of x. The y and z straightness errors of 0.86 and 3.75 μm (3σ) reduced to 0.04 and 0.14 μm, and roll, pitch and yaw errors of 1.6, 6.1 and 3.7 arcsec were reduced to 0.11, 0.63 and 0.30 arcsec in 300 mm of travel range.

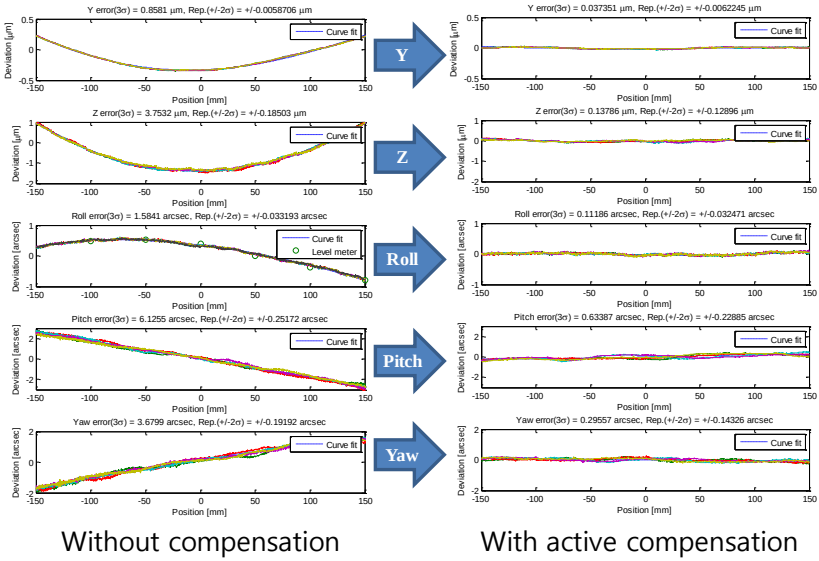

Figure 4: Results of active compensation of motion errors.

3. Conclusion

The proposed air bearing stage was tested for all motion controllability and applied for 5-DOF motion compensation to reduce repeatable motion errors. This stage is expected to be used for ultra precision machine with minimum range of motion errors.

References:

[1] Ro, S.-K., Kim, S., Kwak, Y. and Park, C.-H. "A Linear Air Bearing Stage with Active Magnetic Preloads for Ultraprecise Straight Motion", Precision Engineering, Vol. 34, No. 1, pp. 186 ~ 194, 2010.