6D Magnetic Levitation Positioning System with Compact Integrated 6D Sensor

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Abstract

In semi-conductor industrial processes like wafer handling and wafer inspection mainly large 3D positioning systems with integrated air bearing technology and external interferometric sensor systems are used. This contribution presents a new 6D high precision magnetic levitation positioning system with a very compact integrated 6D sensor system.

1 Introduction

In most applications where magnetically driven systems are used the moving elements are usually mechanically guided by linear guidings or air bearings. Thus, the precision of the sliding element is directly influenced by the precision of the air bearing or the linear guidance. Within the presented 6D magnetic levitation positioning system the guiding, the levitation as well as the driving of the slider is realized using three pairs of coils in combination with three magnetic arrays in a Halbach set-up. In the center of the structure a compact 6D measuring head using capacitive and optical sensors is integrated. Thus, the sensor is located close to the mounting position of the payload and the slider is without any material connection to the surroundings. Due to the force control and no mechanical connection to the surroundings, higher system stiffness and higher system precision can be achieved in comparison to mechanically or air guided systems.

2 System set-up

The mechanical system consists of a slider and a stator. The slider, depicted in Figure 1, comprises a rigid aluminium frame, three Halbach arrays as shown in Figure 2, the sensor grid, and three feet supporting the slider during the initialization

process. The stator comprises a granite base plate in which three pairs of coils are inserted, as depicted in Figure 3. The coils are enclosed in a water cooling pipe structure. Inbetween the triangular set-up of the coils three rectangular metal frames are inserted, acting as hardstops in combination with the supporting feet of the slider.

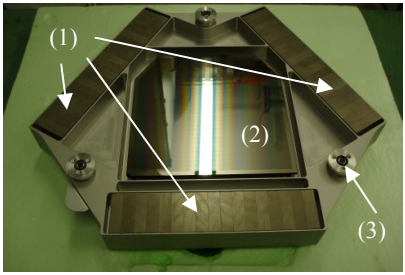

Figure 1: Slider with Halbach arrays (1), sensor grid (2) and supporting feet (3)

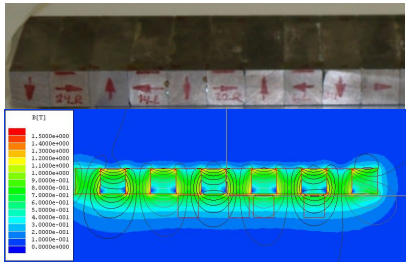

Figure 2: Manufactured Halbach array and its simulated magnetic field

In the center of the base plate a compact measuring head is located, comprising a 3D optical incremental sensor system with a resolution of 5nm for 2D horizontal *x*-*y*- and yaw motion (*w*) as well as PI's capacitive sensors for sensing tip-tilt (*u*, *v*) motion as well as *z*-motion. The capacitive sensors, featuring a resolution of 1nm for the required motion range, are set-up in pairs, as depicted in Figure 4, allowing the measurement against an ungrounded target, according to [1].

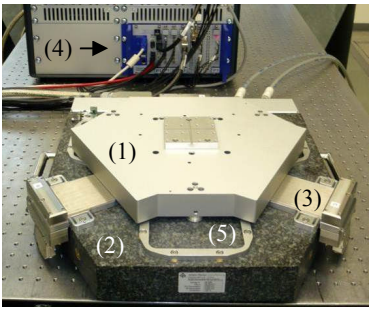

Figure 3: Total system including slider (1), granite base plate of stator (2), coils integrated in cooling sandwich (3), PI's E-712 modular nanopositioning controller (4) and hardstops (5)

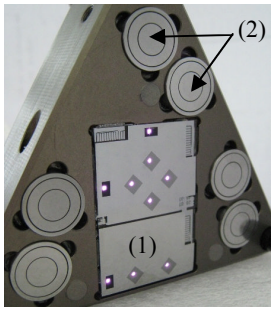

Figure 4: Measuring head with optical incremental sensor (1) and three pairs of PI's capacitive sensors (2)

The control of the system is based upon a PC-ETX processing module of PI's standard E-712 modular nanopositioning controller [2]. In the test set-up the six current loops are connected via SPI (serial peripheral interface) channels. The control algorithm is based on the relation between the current in the coils and the

driving forces onto the Halbach arrays fixed to the slider according to Katzschmann et al. [3]. The commutation required for path control when moving along a given trajectory was calculated preliminary, assuming an ideal set-up of the Halbach arrays in the slider and an ideal set-up of the coils in the stator. These position dependent commutation values were saved as look-up tables in the controller used in the sensor control loop for realizing a smooth path control. Furthermore, the expected heating of the system due to power dissipation within the coils in dependance on the position of the slider was calculated by Katzschmann et al. [3]. Thus, the speed of the cooling fluid was determined and a mean surface temperature difference of the system around 1.5K depending on the position of the slider was achieved.

3 Qualification results

In the following, position stability and motion accuracy of the system are examined. In Figure 5, the position stability of the slider at x=y=0, z = 50µm, the initial position of the system, is depicted. In x- and y-direction, the standard deviation of the position stability is around 3.5nm, about the rotational yaw axis w it is 250nrad. The stability in z-direction lies around 6nm, about u it is 65nrad, about v it is 50nrad.

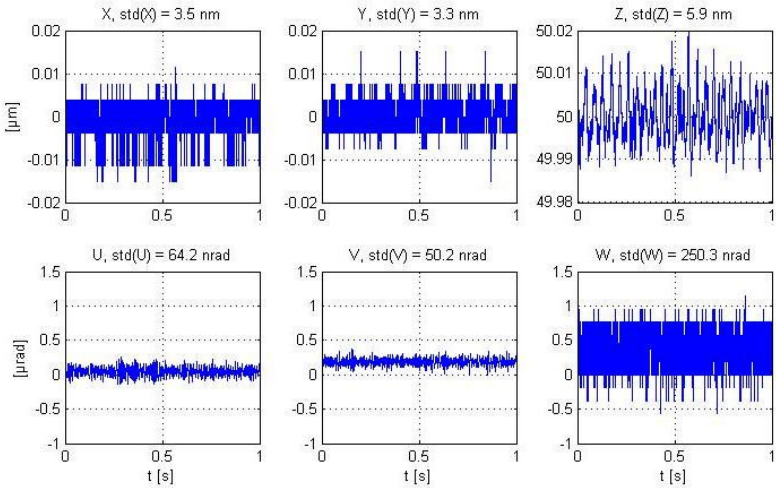

Figure 5: Position stability of the slider at x=y=0, z=50µm; u=v=w=0; data for u, v, and z low-pass filtered (cut-off frequency 400Hz); data for x, y, and w not filtered.

In Figures 6 and 7, the motion accuracy of the slider during a continuous circular motion in the *x*-*y*-plane with radius r=1µm is depicted for one cycle (1s). Along the circular trajectory a very smooth motion is realized. During the motion, the standard deviation of the height of the slider is less than 10nm, the rotational deviations are between 50nrad and 90nrad for tip u and tilt v and around 250nrad for w.

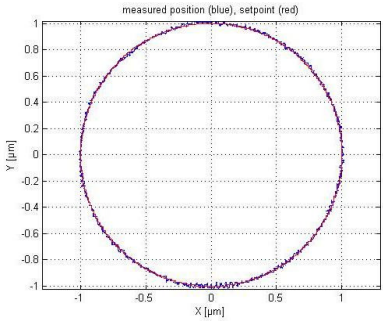

Figure 6: Circular motion in the *x*-*y*-plane with radius r=1µm

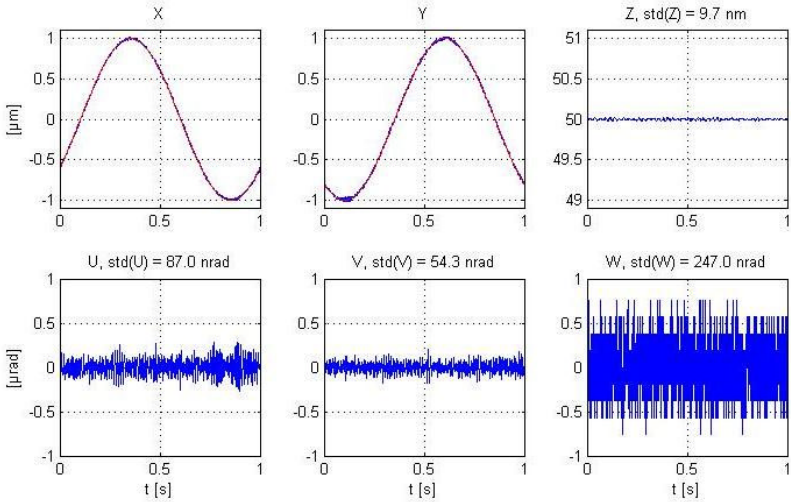

Figure 7: Translational motion accuracy of the slider during a circular motion in x and y with r=1µm, with z=50µm and u=v=w=0; speed V=6.3µm/s ; data for u, v, and z low-pass filtered (cut-off frequency 400Hz); data for x, y, and w not filtered.

Conclusion

A high precision 6D magnetic levitation positioning system with an integrated compact 6D sensor was presented. It is controlled by PI's modular E-712 digital nanopositioning controller, using precalculated commutation tables for the three Halbach arrays for achieving a smooth path control. The first results regarding position stability and motion accuracy are promising. Future work includes the adaption of the measured magnetic fields into the look-up commutation tables,

installation of PWM amplifiers and the improvement of the cooling structure using heat pipes in the stator.

Acknowledgement

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References:

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