Nanometre performance of a 6 DoF MAGLEV system based on 1D*plus* encoders

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Abstract

The design of a MAGLEV stage with one long stroke and five short stroke axes is presented. It uses 1D*plus* encoders as position feedback for the control. Experimental results demonstrate that the system reaches nanometre level stability during standstill and scanning movements.

1 Motivation

The need for nanometre (nm) positioning is reflected in numerous research activities and publications of the last few years [1-4]. Target applications are scanning systems typically used for wafer inspection, that require nm level stability, straightness and smooth motion along the scan axis, while maintaining a high throughput.

The advantages of MAGLEV technology for nm positioning are well-known [3]. It is however important to note that most developments with long strokes use laser interferometers in air, the turbulences of which influence the measurements and therefore disturb the system. The solution presented in this work has one long stroke axis (300mm) and five short stroke axes (±0.2mm air-gap). The system is controlled in six degrees-of-freedom (6 DoF) based on eight actuators and HEIDENHAIN 1D*plus* encoders [5]. This largely reduces the influence of the air turbulences on the system performance.

2 System description

Reaching nm repeatability requires system-level optimization. The mechanical construction, amplifiers, sensors, actuators, controllers, and the active isolation system not only bring their own contribution to the performance, but also their interaction needs to be carefully designed. In addition, it is very important in a MAGLEV system that all components possess a very good signal to noise ratio.

Therefore the use of proprietary components such as ETEL's active isolation system and AccurET VHP amplifiers allow an optimal integration. On the other hand, the combination of 1D*plus* scales and high-end control electronics enhances not only the resolution and the accuracy, but also the speed and the system bandwidth.

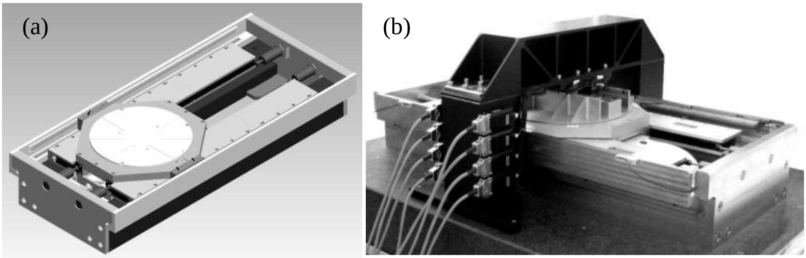

Figure 1: Carriage and axis design (a), set-up with the optional metrology bridge (b)

The stage depicted in Figure 1a is controlled with a 6 DoF controller. A sensor transformation is used to create six decoupled inputs for the 6 DoF that are each controlled with separate controllers, supported by a feed-forward action. An actuator transformation then calculates the force references for the six E-cores and two ironless linear motors. These actions are performed on an industrial PC with xPC Target RTOS, running compiled MATLAB/Simulink® code at 10kHz sampling frequency. Position feedback from all encoders and current set-points for the amplifiers are transmitted using ETEL's proprietary interface TransnET.

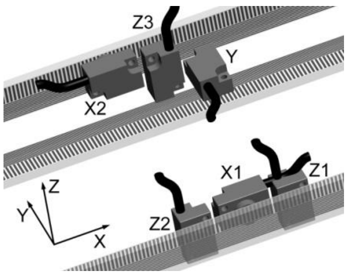

Figure 2: Placing of LIF48 encoder heads with respect to 1D*plus* scales

The six LIF48 encoder heads and three 1D*plus* scales are placed according to Figure 2. The 6 DoF location of the centre of gravity of the carriage can thus be estimated. On start-up however, inductive sensors are used to float the carriage, search for the commutation offset of the ironless linear motors and perform homing. Then the feedback is switched from the inductive sensors to the 1D*plus* encoders.

A second 6 DoF metrology system has been mounted above the carriage, simply for validation purposes as shown in Figure 1b. It comprises eight LIP200 encoder heads and three 1D*plus* scales. This measurement is used only for independently estimating the position of the carriage and does not have any influence on the control. It will be removed later. Using another sensor transformation, the position of the point of interest (PoI) can be estimated, in this case the centre of the wafer chuck. The LIP200 encoders have very low noise levels in the range of 0.1nm RMS in full 3MHz bandwidth so that the stability of the carriage can be accurately measured.

3 Experimental results

3.1 Standstill performance

Table 1 summarizes the experimental results obtained on the test bench during standstill at the PoI and measured using the LIP200 encoders.

Table 1: Positioning error during standstill 3σ @ PoI measured by LIP200

X [nm]	Y [nm]	Z [nm]	Rx [nrad]	Ry [nrad]	Rz [nrad]
1.2	1.2	1.9	17.0	12.7	6.5

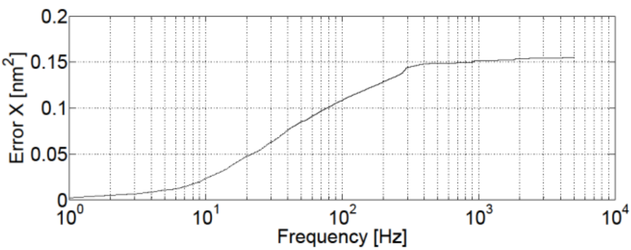

Figure 3: X axis CPS of position error during standstill @ PoI

Figure 3 shows the Cumulative Power Spectrum (CPS) curve of the position error along the X axis. This is a typical example showing that the residual noise is spread over the spectrum up to the bandwidth of the position controller. The absence of any main contribution in the error spectrum is the result of control over each individual system component, and their high level of integration.

3.2 Scanning performance

Table 2 summarizes the results for a 40 mm/s scanning movement along the principal axis. As depicted in Figure 4, these results take solely into account the movement at constant speed. With respect to the standstill results, some additional tracking error is observed. These are related to position dependant behaviours such as periodic disturbances of the linear motors and dynamic effects in the cable chains. Encoder scale mapping also still needs to be implemented.

Table 2: Positioning error during scan at 40 mm/s 3σ @ PoI measured by LIF48

X [nm]	Y [nm]	Z [nm]	Rx [nrad]	Ry [nrad]	Rz [nrad]
9.3	4.3	11.0	76	110	32

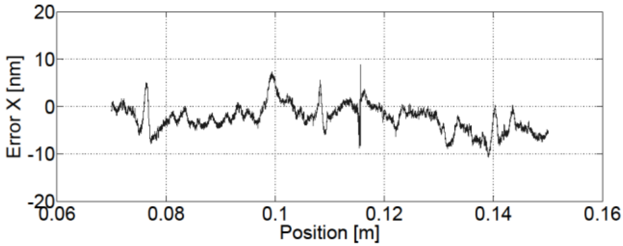

Figure 4: Error versus position during a scan at 40 mm/s @ PoI

4 Conclusion and Outlook

A 6 DoF MAGLEV scanning device using 1D*plus* encoders as position feedback has been designed to meet wafer fab inspection equipment requirements. Future work includes reducing the disturbances in the system and improving the performance of all components. The LIF48 encoders can also be replaced by LIP200.

References:

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