# Measuring the Deformation of a Magnetically Levitated Plate

## Ultra-Precise Displacement Measurement of 25 Axes with Multiple IDS3010

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Deformations in lightweight moving structures such as the wafer stages in semiconductor lithography systems hinder the fabrication process with a high throughput rate. To compensate for these deformations, accurate measurements are required. Coen H. H. M. Custers and Ioannis Proimadis at the Eindhoven University of Technology designed a prototype based on attocube's interferometer IDS3010 to study these properties in more detail [1]. A grid of 5 x 5 M12/F40 sensor heads detects the deformation of the mover inside a bearingless planar motor with nanometer accuracy. By accurately detecting the induced deformation, the goal of the experiment was the active attenuation of the deformation by properly shaping the force distribution on the magnetically levitated translator.

## Introduction

Flexible body dynamics are present in every mechanical structure and are often sufficiently described by the rigid body dynamics: the deformation resulting from the flexible behavior is negligible with respect to the target accuracy. This behavior is additionally amplified by stiff and heavy constructions. In many positioning systems though, *e.g.* the wafer stage in the semiconductor lithographic industry, nanometer accuracy is demanded, while high throughput rates are facilitated by resorting to lightweight structures. In such cases, incorporating the flexible body dynamics is crucial to meet the desired performance goals.

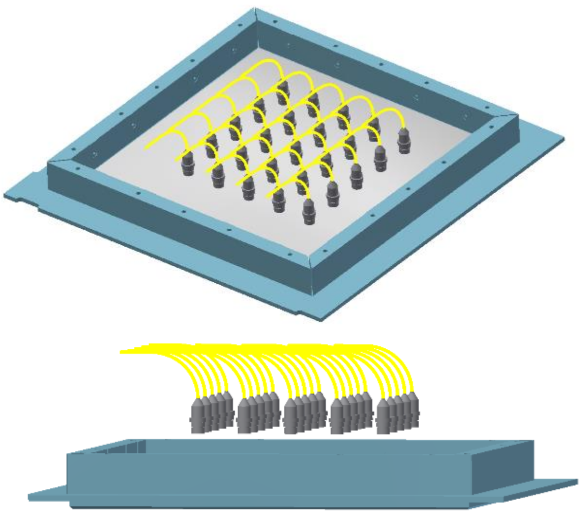

*Figure 1: Sketch of the magnetically levitated plate and the sensor grid placed above it.*

One of the typically used motion systems for high-precision positioning is the bearingless planar motor. In this planar motor, the moving part is stably levitated and positioned in six degrees-of-freedom by means of magnetic fields. Eindhoven University of Technology has designed and developed a planar motor, where the mover consists of a flat plate with a permanent magnet array on the bottom. Theoretical studies showed [2] the force exerted on the magnets during levitation and propulsion causes the mover to deform (on micrometer level). The deformation is performed mainly in the direction perpendicular to the flat surface of the plate.

With the goal of nanometer positioning accuracy, the suppression of this outer-plane deformation is required. To this approach, a measurement platform using a detection technique with sub-nm resolution became necessary to analyze the deformation. Such an analyzing tool was designed and will be described in the following.

## Setup

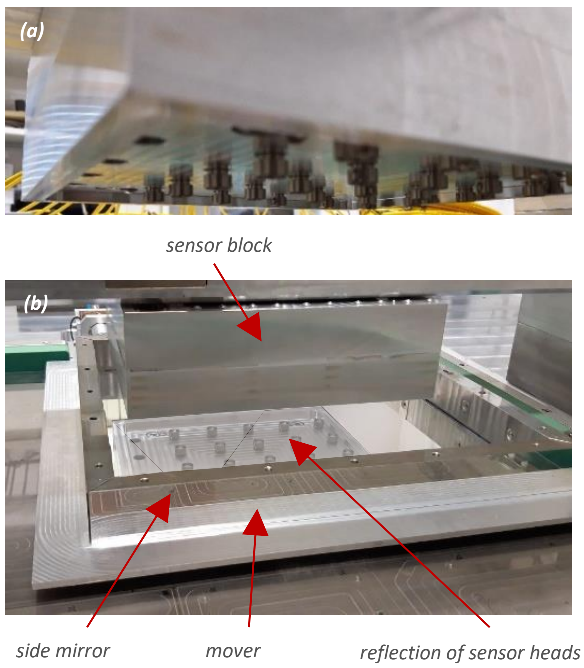


*Figure 2: Picture of the measurement setup. (a) Bottom view of the sensor block with the sensor heads. (b) View of the mover with mirrors and the sensor block mounted above it. The reflection of the sensor heads can be partly seen in the top mirror of the mover.*

The requirement of contact-free and fast measurement devices and the possibility of deformation measurements for a detailed analysis is fulfilled by the IDS3010 with M12/F40 sensor heads. The focused M12/F40 sensor heads are capable of measuring on both low-reflective targets (*e.g.* glass) and high-reflective

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targets (*e.g.* mirrors). With a working range of a few millimeters, these sensor heads offer of relatively high angular tolerance specified with ± 0.35°. Besides the nanometer accuracy, especially the real-time capability in combination with a bandwidth of up to 10 MHz made the IDS3010 a perfect tool for measuring deformations of the wafer mover. The test measurements were performed at ambient conditions while the IDS3010 with its optical components is capable for high or ultra-high vacuum measurements.

A grid consisting of 5 x 5 sensor heads is installed directly above the magnetically levitated plate as shown in Figure 1. The sensor heads are mounted in a solid aluminum block attached to a vibration-isolated metrology frame and reflect on a square mirror placed on top of the plate (see Figure 2). The grid covers only part of the plate to allow in-plane movement of 80 mm x 80 mm without losing the signal.

## Measurement Results

Since the absolute flatness of the top mirror of the mover is unknown, the measurement system can instead be used to measure the change in deformation between two different actuation settings of the motor. Here, the different settings were defined using the feedforward control of 40 individually excited coils and are capable of changing the shape and the vibrations of the levitated plate.

Based on simulation results, four flexible modes of the magnetically levitated plate were identified. The proposed approach has been experimentally validated, managing to successfully minimize the deformation induced by these four modes [1].

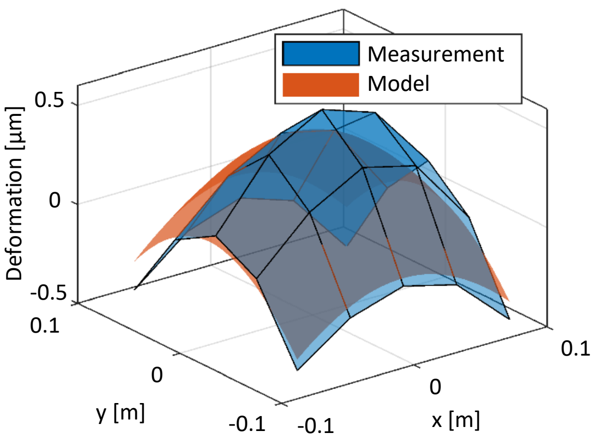


*Figure 3: Absolute measured difference on the 25 sensor heads when the deformation of the magnetically levitated plate is minimized with feed-forward control.*

Taking one of the four modes (the umbrella mode) as an example, the 25 sensor heads of the IDS3010 were used to measure the difference between the non-minimized and minimized case (Figure 3, blue surface). In addition, the measurement is compared with the predicted result using the simulation model (Figure 3, orange surface). The maximum measured deformation reduction is equal to 544 nm. The root mean square (rms) error between the predicted response and the measurement is equal to 101 nm.

## Conclusion

To measure the deformation of a magnetically levitated plate in a planar motor, a measurement system using nine IDS3010 was designed and constructed. The 25 sensor heads were placed into a grid mounted above the magnetically levitated plate, which has a mirror on the top side. Using the developed measurement system, deformation minimization of the plate by feedforward control was experimentally demonstrated on the planar motor.

### References

[1] C.H.H.M. Custers, I. Proimadis, J.W. Jansen, H. Butler, R. Tóth, E.A. Lomonova, and P.M.J. Van den Hof, "Active compensation of the deformation of a magnetically levitated mover of a planar motor" in 2019 IEEE International Electric Machines & Drives Conference (IEMDC), San Diego, USA, 2019.

[2] J.M.M. Rovers, J. Achterberg, M.J.C. Ronde, J.W. Jansen, J.C. Compter, E. Lomonova, C.M.M. van Lierop, M.J.G. van de Molengraft, "The deformation of the moving magnet plate of a commutated magnetically levitated planar actuator", *Mechatronics*, vol. 23, no. 2, pp. 233-239, 2013.