# Design and control of a through wall 450 mm vacuum compatible wafer stage

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## Abstract

High precision machines such as EUV wafer scanners and E-beam measurement systems require a high vacuum level. Contamination of this vacuum due to moving cables and bearings of the positioning stages within are an issue. An inverted planar motor solves this contamination issue but leads to a complex system due to position dependant commutation and a large number of coils [1]. Therefore an alternative stage design is made at MI-Partners (see Figure 1) which has a low degree of complexity and does not cause contamination of the vacuum. In this concept a separation has been made between two vacuum levels: a clean/precision vacuum and a non-precision/dirty vacuum. The separation between the two is realized by a wall. The design uses a Short Stroke-Long Stroke (SS-LS) stage configuration where the SS stage makes its actuation forces through the wall. The precision vacuum contains the SS chuck carrying a wafer for manufacturing or inspection. In the non-precision vacuum a conventional stacked LS x-y stage is placed. The function of this XY stage is to enable a larger stroke for the short stroke system. The vacuum underneath the separator plate is only required to minimize loads on the wall due to the pressure difference over a large area. In this paper the design of a demonstrator and its control architecture is described.

## 1 Through Wall Actuators

The through wall stage concept requires the development of new actuators due to the large air gap introduced by the wall. To minimize the complexity of the actuators, the functionality of suspending and propelling the SS stage is split into two separate

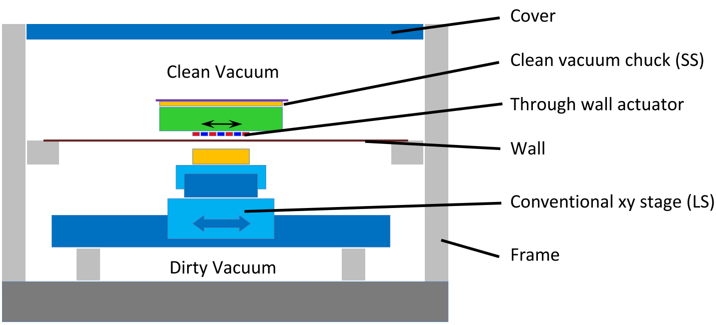



Figure 1 Through wall vacuum wafer stage design, showing the separation between a precision/clean and a non-precision/dirty vacuum compartment, as well as the Long Stroke Short Stroke stage configuration.

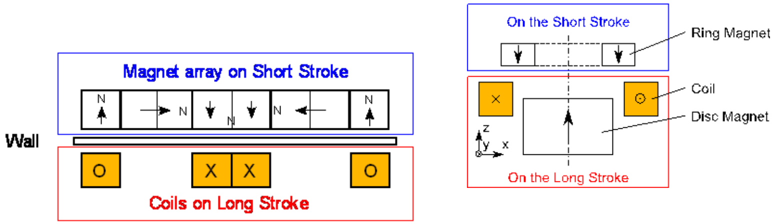
actuators units: an in-plane actuator and an active magnetic gravity compensator (Figure 2).

### 1.1 Active Magnetic Gravity Compensator

The active magnetic gravity compensator holds the weight of the stage using passive magnets and enables actuation using a coil on the LS side. The magnets minimize power consumption for carrying the weight, but potentially adds actuator stiffness. As the long stroke stage is envisioned to be a conventional stage without high requirements, the transfer of disturbances and therefore actuator stiffness should be minimized. To realize this, a low stiffness gravity compensator was developed using a circular magnet with a hole in the center. The design principle of the zero stiffness effect is explained in Figure 2.

### 1.2 In-plane Actuator

The in-plane actuator is based on a Halbach magnet arrangement. The Halbach array ensures the magnetic fields is “pushed” towards the LS stage (Figure 2). The design was optimized to minimize position dependency; it can be operated without the need of commutation.




In-plane motor　　　　Active Gravity Compensator

Figure 2 Custom motor designs for In-plane and out of plane actuation.

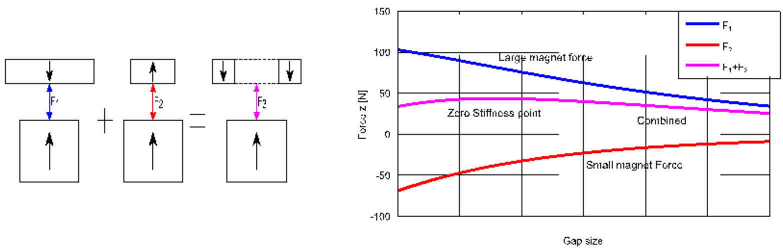



Figure 3 Working Principle of Active Magnetic Gravity Compensator. The ring shaped magnet with force $F_3$ can be seen as the superposition of a larger magnet (force $F_1$) with opposite polarisation and a smaller magnet with attractive polarization (force $F_2$), resulting in zero stiffness behaviour.

## 2 Design and Control Integration

To demonstrate the potential of the through wall concept a demonstrator has been realized. The goal of the demonstrator is not to reach nm-precision but to show the concept. The design consists of a 450 mm Short Stroke wafer chuck. This chuck is actuated using four in plane actuators and four active gravity compensators. This leads to an over-actuated system. The advantage of over-actuation is reduced excitation of the torsional mode, which typically limits performance of large chucks [2], see Figure 8. The stage is measured in 6 DoF with respect to a metrology frame and is controlled using a decoupled controller around the SS's center of gravity. A bandwidth of 100 Hz has been achieved on all directions. The long stroke stage tracks the SS stroke stage. The long stroke is actuated by a spindle drive. To minimize visibility of spindle stage dynamics through the reaction path of the short stroke stage, the metrology frame is isolated at 10 Hz using passive rubbers. Currently the design has only one long stroke direction, but a stacked XY stage can easily be added to the system. A recent development has been a wireless energy system towards the SS stage.

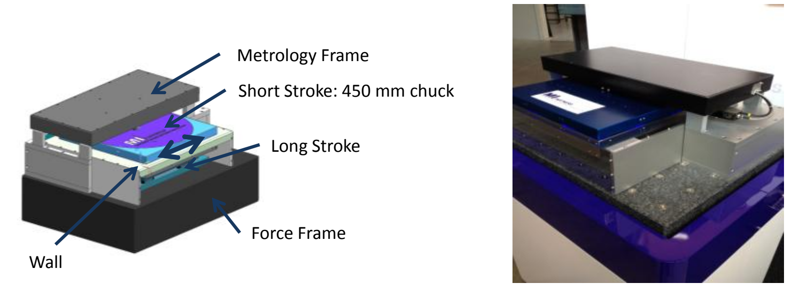



Figure 4  Mechanical layout of the system (left), image of the demonstrator (right).

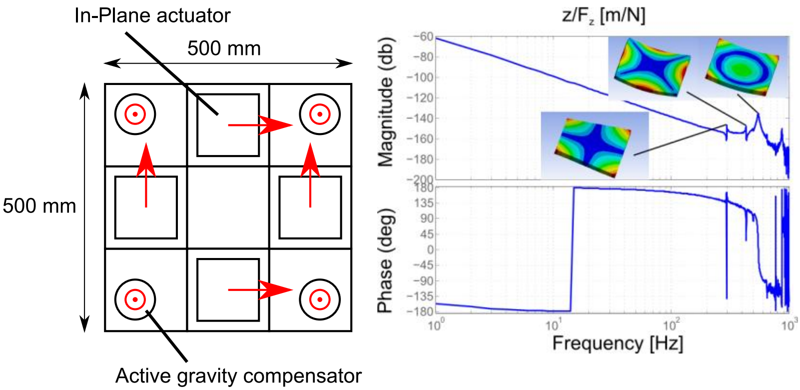



Figure 5 Actuator layout of SS chuck (left). FRF of Short stroke stage in Z direction (right). Torsional mode at 300 Hz is only mildly excited because of over-actuation.

**References:**

[1] J.W. Jansen. “Magnetically levitated planar actuator with moving magnets: Electromechanical analysis and design”, PhD thesis, TU Eindhoven , pp. 5

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