Lightweight 450 mm Wafer Stages Enabled by Over-actuation

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Abstract

Wafers with a diameter of 450 mm are one of the future challenges for the semiconductor manufacturing industry. The increased wafer size leads to an increased size of the positioning stages and chucks. Because of the desire to keep internal flexible modes at high frequencies, the wafer chuck tends to increase significantly in thickness and mass. To maintain throughput, higher acceleration forces are needed to accelerate these heavier chucks. Large actuation forces cause unwanted heat generation and excitation of accurate machine components. An alternative solution is to apply over-actuation to these positioning systems. In over-actuation more actuators are used than degrees of freedom (DoF). While over-actuation promises a reduction of weight at high levels of performance, it does so at the cost of additional control complexity. In this paper a method of over-actuation is presented where the added complexity is limited and a significant step in performance is made.

1 Simultanious topology and optimisation control of over-actuated chuck

Conventionally wafer chucks have actuators equal to the amount of rigid body Degrees of Freedom (DoF). Active position feedback loops are used to stabilise the system and reach positioning performance. One of the limits on the feedback performance is imposed by the excitation of internal flexible modes of the wafer chuck in the plane perpendicular to the wafer. For a 450 mm chuck to reach similar internal eigen-frequencies of a contemporary 300 mm chuck, a significant increase of the chuck thickness is required. It is well known in mechatronics that by placing actuators in the node of flexible modes, specific flexible modes are not excited, see Figure 1. In a mechanical structure there exist infinitely many mode shapes and nodes. To fully exploit this, infinitely many actuators are required and the control complexity increases significantly. An alternative is to optimise the mechanical

structure of the wafer chuck such that the nodes of several critical flexible modes coincide and a limited amount of additional actuators can be used.

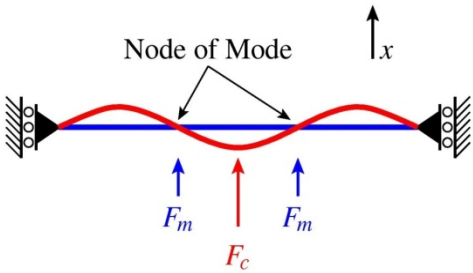

Figure 1: Conventional actuation, Fc, results a rigid body displacement in x-direction and excitation of the flexible mode. Over-actuated actuation, Fm, results in a rigid body motion and does not excite this flexible mode.

A topology optimisation, as discussed in Lit 1, was used to simultaneously optimise the mechanical structure and actuator placement. The optimisation was performed for the 3 critical directions of the wafer chuck in the plane perpendicular to the wafer (Z, Rx, Ry). The structural and actuator placement optimization technique showed that by using just 4 actuators acting on 3-DoF, a significant improvement in performance could be achieved compared to conventional actuation in the 3 Bessel's points. The control strategy for the over-actuated chuck is shown in Figure 2.

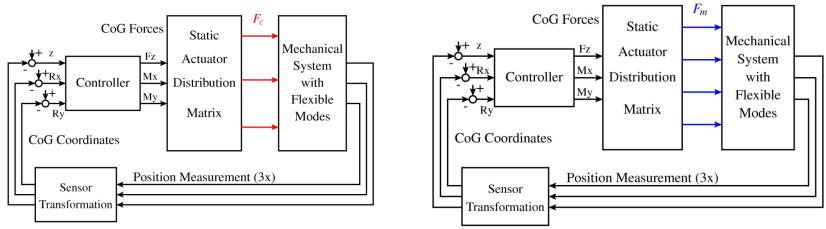

Figure 2: Control strategy of conventional wafer chuck (left), and over-actuated chuck (right). Only limited complexity is added for over-actuated system. Note that the number of sensors remains the same.

2 Prototype of over-actuated chuck

A demonstrator for evaluating the performance of an over-actuated 450 mm wafer chuck in the most critical directions (z, Rx, Ry) has been developed at MI-Partners. Figure 3 shows the 450 mm over-actuated wafer chuck having only a weight of 7 kg. The system has 3 DoFs, namely Z-translation and rotations Rx, Ry, the other DoFs are constrained by the plate springs. Three linear encoders, equal to the number of DoF, are used to measure the position of the chuck. The demonstrator can be operated under conventional actuation (3 actuators) and over-actuation (4 actuators). The 4 actuators, encircled by the dark line, are used during over-actuation; the 3 actuators, encircled by the light line, are used for conventional actuation, see Figure 3. The actuators are suspended in a highly damped rubber membrane to avoid excitation of the flexible modes in the base frame.

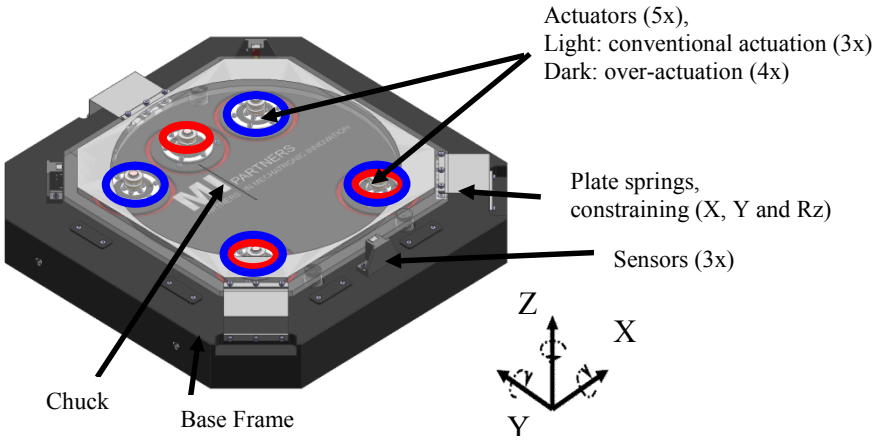

Figure 3: Over-actuated wafer chuck, Light circles indicates the actuators which are used during conventional actuation, while dark circles indicate the actuators used for over-actuation.

3 Performance of chuck

The advantage of the over-actuated system is illustrated in Figure 5, where the plant FRF for the conventional actuation and for over-actuation is shown in the Ry direction. The conventional system has a typical -2, -4 slope characteristic having a performance limit caused by the flexible mode at 180 Hz. The over-actuated system

possesses a -2 slope up to 800 Hz. The remaining excitation of the flexible mode at 180 Hz during over-actuation results from the chuck's manufacturing tolerances and low mechanical damping. The control bandwidths can be improved by a factor 4 up to 200 Hz, resulting in a low frequency error suppression improvement by a factor of 16. With this, the light weight over-actuated 450 mm wafer chuck shows that it is capable of achieving similar performance to a contemporary conventionally-actuated 300 mm wafer stage.

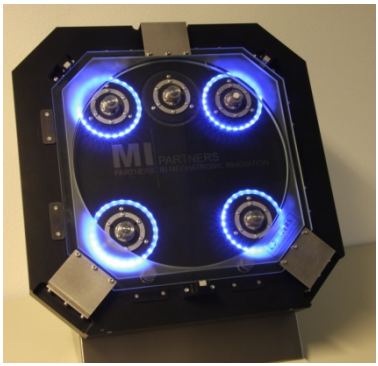

Figure 4: Image of over-actuated chuck

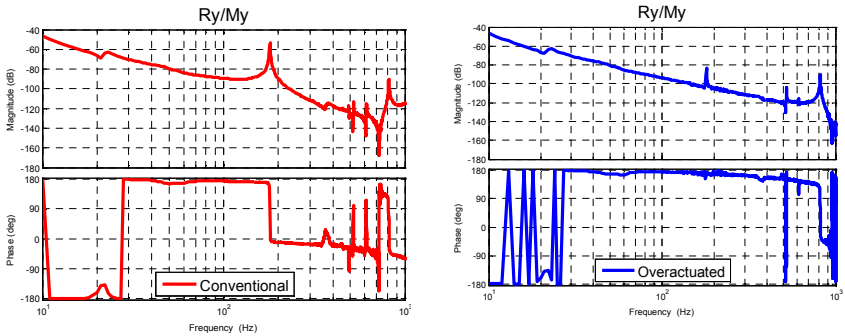

Figure 5: Left - measured FRF Ry/My of conventional actuated system, Right - measured FRF Ry/My of over-actuated system,

References:

[1] Langelaar M., Exploratory Investigation into Topology Optimization of Overactuated Systems, Delft University of Technology research report, December 2008