

Nullifying Acceleration Forces in Nano-Positioning Stages for Sub-0.1mm Lithography Tool for 300 mm Wafers

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Introduction

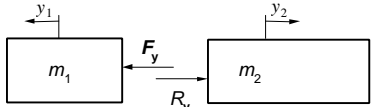
The transition of the semiconductor industry from the current 200 mm wafers to the larger 300 mm wafers has presented considerable challenges to all equipment suppliers, in particular the lithography tool manufacturers. Not only are the moving masses of nanometer-positioned wafer stages increases by up to a factor of 3.4, but accelerations are also to be doubled in order to maintain the same number of exposed wafers per hour. The driving forces in nanometer-positioned stages have to be increased by a factor of 5 or more, even with extensive weight reduction by use of unconventional structural materials. For example, the maximum driving force in the scan direction in the latest 300mm-wafer lithography platform exceeds 1kN. This level of actuation forces is close to the limit of conventional dynamic architecture of lithographic equipment, in which the reactions are connected to 'ground' via a so-called force frame (Fig. 1).

To design a machine platform that is extendable well beyond the 70-nm node, means of nullifying the acceleration forces is highly desirable if not essential.

Theory

The use of a frictionless, counter-moving mass for nullifying reactions to acceleration forces is not new, as has been implemented for decades in firearms and artilleries. The application of this simple concept in nano-positioning stages not only has the same effect of reaction force cancellation, but also has the additional advantage that the centre of mass of the combined system remains stationary, thus also significantly reducing vertical disturbances to the rest of the machine.

Working principle is simple -- reactions to acceleration forces are channelled to a so-called balance mass free to move, in the specific degree(s) of freedom, in the opposite direction with min. friction. The ratios of accelerations and displacements between the moving object and the balance mass both equal the inverse of the mass ratio :

$$m_1 \cdot \ddot{y}_1 = m_2 \cdot \ddot{y}_2 \quad \text{or} \quad m_1 \cdot y_1 = m_2 \cdot y_2$$


The challenge is to implement such an inertia balancing system in multiple degrees of freedom.

Embodiment 1 -- Reticle Stage Balancing in 6 Degrees of Freedom

While the latest generations of wafer and reticle positioning stages are servo-controlled to nanometer accuracies in all six degrees of freedom, movements with long ranges and high forces rarely exceed 2 or 3 degrees of freedom. For example, the reticle stage essentially move in long range and high acceleration only in the scanning (y) direction, while movements and forces in the other five degrees of freedom are small. As such a single balance mass as shown above with friction-free movement in the same direction would suffice. The use of two balance masses on each side, however, offers additional balancing possibilities against yawing moments through differential movements between the two balance masses. Minute movements in the other 4 degrees of freedom can also be effected on the same masses by supporting them in those directions compliantly.

The embodiment can be summarised as follows:

Transmission of Forces & Moments from Reticle Stage to Balancing System

F_x	via thrust bearings between Long Stroke Module (LoS) & Balance Mass (BM)
F_y	through linear motor in scan direction (mover on LoS, magnet plates on BM)
F_z	via thrust bearings between LoS & BM
T_x	differential vertical forces on thrust bearings between LoS & BM
T_y	differential vertical forces on thrust bearings between LoS & BM ₁ .
T_z	differential Y-forces between LoS & BM, as in F_y .

Balancing Methods

F_x	compliant support for BM	F_y	long-range balance-mass movements
F_z	compliant support for BM	T_x	compliant support for BM
T_y	compliant support for BM	T_z	diff. balance-mass movements

Embodiment 2 -- Wafer Stage Balancing in 3 Degrees of Freedom

A similar scheme can also be applied to the wafer stage. The latter has, however, major movements in at least 2 degrees of freedom (two orthogonal directions in the plane of the wafer). An open-frame type balance mass, free to move in the above-mentioned plane in a frictionless manner, can be used for the said balancing purposes. An additional freedom for yaw movement has to be allowed for to accommodate off-centre reaction forces.

The embodiment can be summarised as follows:

Transmission of Forces & Moments from Wafer Stage to Balancing System

F_x	via thrust bearings between Long Stroke Module (LoS) & Balance Mass (BM)
F_y	through linear motor in scan direction (mover on LoS, magnet plates on BM)
F_z	via thrust bearings between LoS & BM
T_x	differential / off-centre vertical forces between LoS & BM (thrust bearings)
T_y	differential / off-centre vertical forces between LoS & BM (thrust bearings).
T_z	differential Y-forces between Long Stroke & Balance Masses.

Balancing Methods

F_x	long-range balance-mass movements	F_y	long-range balance-mass movements
F_z	(optional) compliant support for BM	T_x	(optional) compliant support for BM
T_y	(optional) compliant support for BM	T_z	balance-mass yaw movements

Experimental Verification

Figure 4 shows unfiltered servo error plots superimposed on velocity profiles. The first chart shows reticle stage (RS) servo error in the scan direction, with RS at standstill and wafer stage (WS) at full acceleration. The second chart shows the reverse. As can be seen, no obvious cross talk between RS and WS can be observed, demonstrating the effectiveness of the balancing systems.

Conclusions

The use of inertia balancing results in much improved machine dynamics and simplifies the design of the machine structure considerably. Experimental results have demonstrated the effectiveness of the balancing system in reducing the cross talk of different moving stages sharing a common machine platform. It has been demonstrated that such a balancing system can be implemented with long-range movements in at least 3 degrees of freedom.

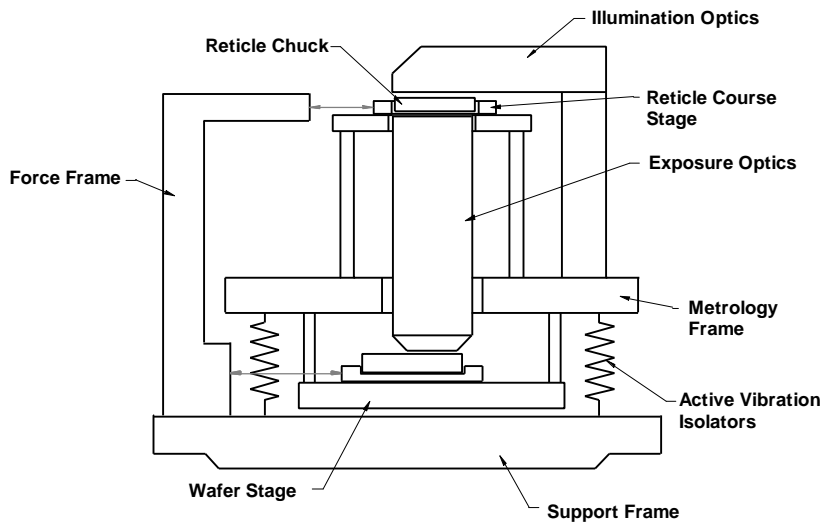


Fig. 1 Dynamics Architecture of an ASML PAS 5500 Scanner
(Actuator Forces transmitted to a Force Frame)

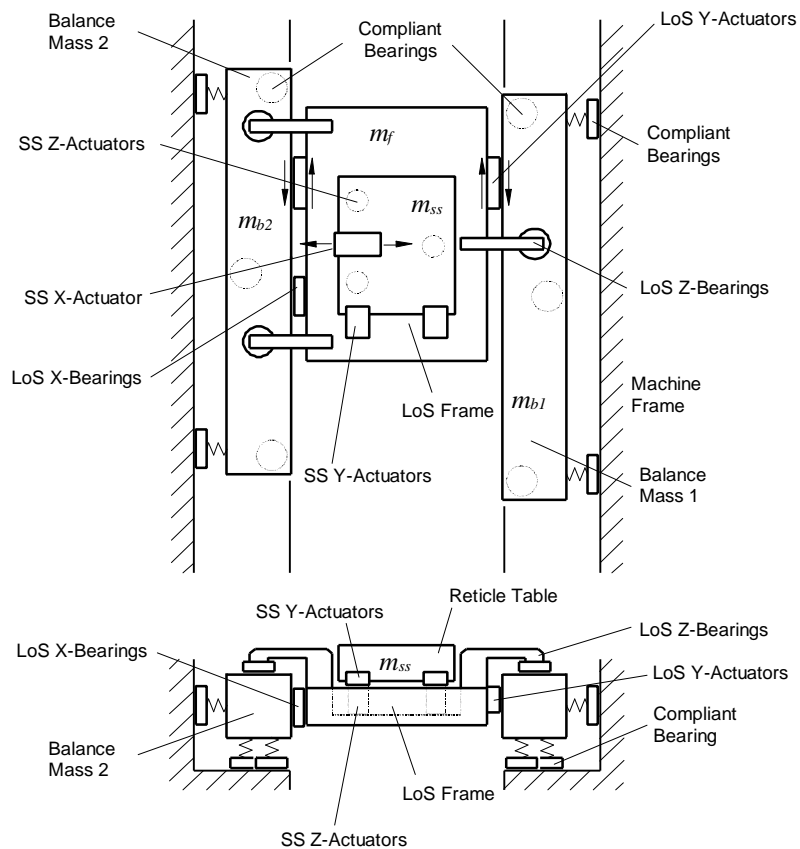


Fig. 2 6 Degrees-of-Freedom Balancing for a Reticle Stage

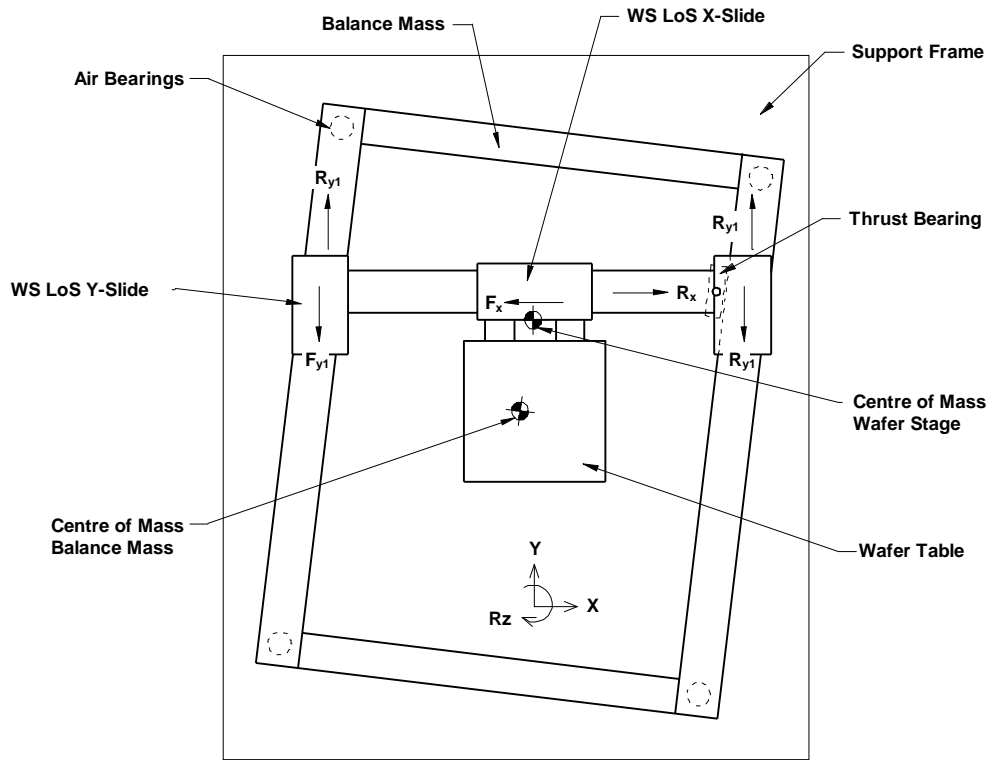


Fig. 3 Long-Range Balancing in 3 Degrees of Freedom for a Wafer Stage

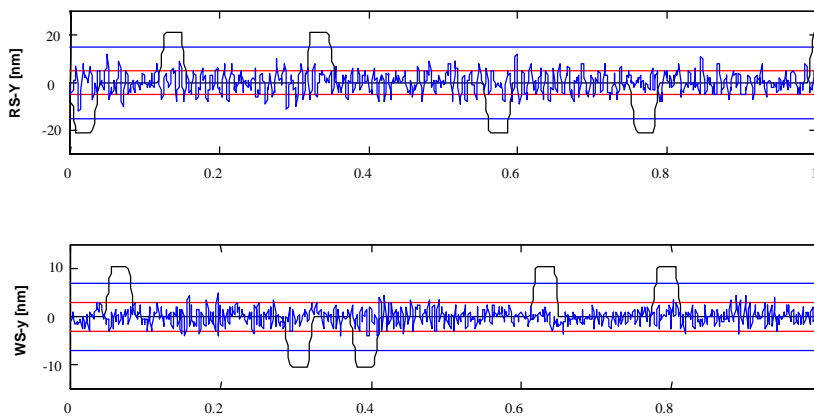


Fig. 4 Servo Error Plots for Reticle and Wafer Stages