Inferential control of a wafer stage using disturbance observers

Noud Mooren [1,*], Nic Dirkx [2], Robbert Voorhoeve [1], Tom Oomen [1]
[1]Eindhoven University of Technology, Dept. of Mechanical Engineering, Control Systems Technology, The Netherlands
[2]ASML Research Mechatronics, Veldhoven, The Netherlands. *Email: n.f.m.mooren@tue.nl

1 Background and problem definition

In high-precision motion systems it is often not possible to directly measure at the location where performance is required. Therefore, performance variables need to be inferred from non-collocated sensor measurements. If flexible behavior is negligible, a static sensor transformation is used to find a rigid-body (RB) approximation of the performance variable. However, for next-generation motion systems positioning accuracy is ever-increasing, leading to a situation where flexible dynamics are not negligible. As a result, traditional single degree-of-freedom (DOF) controllers are inadequate [1]. The aim of this research is to control the unmeasured performance variable while taking flexible behavior into account, through 2-DOF controller structures and disturbance observers.

2 Approach

An explicit distinction is made between measured variables, denoted with y_p, and performance variables denoted with z_p [1]. The control goal is stated as; *track a reference r_z in the unmeasured performance variable z_p, while taking structural deformations into account.* The structural deformation, possibly induced by a (quasi-static) disturbance, causes a RB-estimation of the performance variable to be inaccurate, as in the schematic representation in Fig. 2. The proposed method extends the single DOF controller structure with a disturbance-based observer, as depicted in Fig. 1. The disturbance-observer estimates the disturbance and uses it to create an improved estimate of the performance variable denoted with $\hat{z}_p$ [2]. A feedback controller K_{fb} is designed that minimized the error $e_{\hat{z}}$. Finally, the observer-based controller K_{obs} is given by

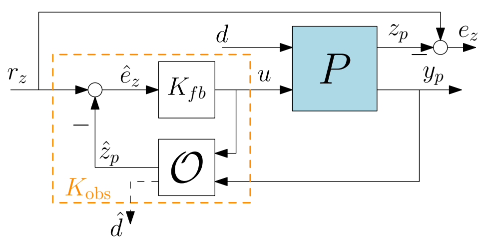

Figure 1: Disturbance observer-based controller structure.

$$u = S_{\mathscr{O}} \begin{bmatrix} K_{fb} & -K_{fb}\mathscr{O}_2 \end{bmatrix} \begin{bmatrix} r_z \\ y_p \end{bmatrix} \quad (1)$$

with $S_{\mathscr{O}} = (I + K_{fb}\mathscr{O}_1)^{-1}$, $\mathscr{O}_1(s) : u \mapsto \hat{z}_p$ and $\mathscr{O}_2(s) : y_p \mapsto \hat{z}_p$.

3 Experimental results

The proposed observer-based method and the conventional method, i.e., using PID controllers, are applied to a prototype light-weight wafer stage in Fig. 2. A force disturbance and position reference are applied, the resulting positioning error $e_z = r_z - z_p$ for both controllers are depicted in Fig. 3. It can be concluded that the proposed method eliminates the steady-state error which is caused by the deformation, whereas the conventional controller is not capable of dealing with the deformation.

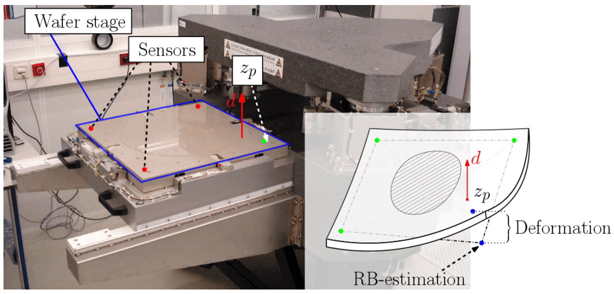

Figure 2: Prototype wafer stage and schematic representation.

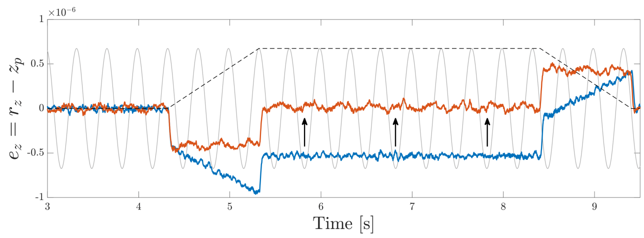

Figure 3: Positioning error e_z obtained with conventional controller (blue) and inferential controller (red), reference (gray) and disturbance (dashed gray).

References

[1] J.S. Freudenberg, C.V. Hollot, R.H. Middleton: "Fundamental design limitations of the general control configuration", IEEE Transactions on Automatic Control (2003)

[2] R. Voorhoeve, N. Dirkx, T. Melief, W. Aangenent, T. Oomen: "Estimating structural deformations for inferential control: a disturbance observer approach", IFAC Symposium on Mechatronic Systems & 15th Mechatronics Forum International Conference, 642-648 (2016)