Inferential control of a wafer stage using disturbance observers

Noud Mooren 1,∗, Nic Dirkx 2, Robbert Voorhoeve 1, Tom Oomen 1
1Eindhoven University of Technology, Dept. of Mechanical Engineering, Control Systems Technology, The Netherlands
2ASML 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 $e_z$. Finally, the observer-based controller $K_{obs}$ is given by

$$u = S_O \left[ K_{fb} - K_{fb} O_2 \right] \begin{bmatrix} r_z \\ y_p \end{bmatrix}$$ (1)

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 1: Disturbance observer-based controller structure.

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