Dealing with Flexible Modes in 6 DOFs Robust Control

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1 Introduction

New trends in lithography for IC production lead to developments in mechatronic stage designs. The trends in lithography are

- new light sources ⇒ operation in vacuum
- finer patterns ICs ⇒ higher accuracy
- increased throughput ⇒ aggressive movements.

In IC production, a wafer stage positions the wafer, containing the to-be-produced ICs, with respect to the imaging optics in all six degrees-of-freedom (DOFs), see Fig. 1. A contactless operation of the wafer stage is desirable both for the vacuum environment and for achieving high accuracy. The need for a gravity compensation in contactless operation and more aggressive movements motivate **lightweight** stage designs.

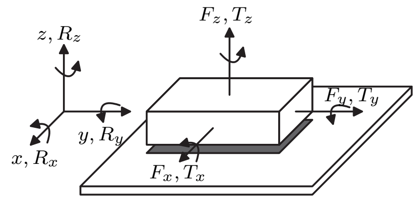

Figure 1: DOFs in a mechatronic stage.

2 Control perspective

A lightweight stage design typically results in a flexible structure. Present state-of-the-art control designs mainly address the rigid-body behaviour. Higher performance can be achieved by explicitly addressing the flexible behaviour of the plant during control design, *e.g.*, compensating the position-dependent behaviour of the structure due to movements, using inferential measurements ($z \neq y$) since the position where performance is desired is not measured, and compensating flexibilities by means of overactuation/oversensing.

3 Hypothesis

High performance flexible stages mainly exhibit linear dynamics due to an almost perfect mechatronic design. At nanometer scale, nonlinear effects will be present throughout the entire actuation chain that are largely reproducible. The flexible behaviour of the plant can be compensated for to a certain limit. In particular, the behaviour of the plant can only be predicted to a certain extent. In this research, the limits for compensating flexible behaviour are investigated. Additionally, these limits may be relocated by increasing the number of actuators and sensors.

4 Approach

The present research, which is continuously and interactively supported by experimental results, focusses on:

1. *Experimental modeling* of mechanical systems is effective, since the measurements are reproducible, fast, and inexpensive. In a model-based control design approach, compensation of more complex dynamics requires more complex models. Present state-of-the-art tools are mainly restricted to SISO systems. The present research focusses on an experimental and closed-loop relevant identification approach that can reliably handle six degrees-of-freedom with flexibilities. Improving the numerical performance of the algorithms, *e.g.*, by using orthogonal vector polynomials or orthogonal rational functions [1], appears to be key in developing multivariable modeling tools.

2. An *experimental validation* confirms a more complex model indeed is more accurate for the desired task. Furthermore, it reveals the limits of the tools used during experimental modeling and the limit of reproducibility of the system. Similar validation experiments should be performed if position-dependent models are used, *e.g.*, those arising from interpolating several linear models. Additionally, quantification of the remaining uncertainty should be performed by means of an experimental validation-based uncertainty modeling approach.

3. A *robust control* design should be made based upon the nominal model of Step 1 and the uncertainty model of Step 2. The achieved closed-loop performance should again be validated. If the expected performance is not achieved, the nominal model or uncertainty model can be modified. Additionally, a direct controller tuning can be considered. The robust control design should reveal performance limitations due to the presence of both flexibilities and uncertainty.

References

[1] A. Bultheel, M. Van Barel, P. Van gucht, *Orthogonal basis functions in discrete least-squares rational approximation*, J. Comp. Appl. Math. 164-165:175-197 (2004).