High Performance Beyond-Rigid-Body Control of Next-Generation Flexible Stages

Tom Oomen, Robbert van Herpen, Okko Bosgra
Eindhoven University of Technology
Department of Mechanical Engineering
Control Systems Technology Group
PO Box 513, WH -1.129
5600 MB Eindhoven, The Netherlands
T.A.E.Oomen@tue.nl, R.M.A.v.Herpen@tue.nl, O.H.Bosgra@tue.nl

Marc van de Wal
Philips Applied Technologies
Mechatronics Department
High Tech Campus 7, 1 A.036
5656 AE Eindhoven, The Netherlands
M.M.J.van.de.Wal@philips.com

Abstract

Vacuum operation and increasing performance requirements lead to the design of lightweight stages. As a result, stages become flexible and exhibit internal deformations while tasks are performed. The aim of this research is to accept and explicitly compensate for the flexible plant behavior in control design. Control techniques that explicitly address flexible plant behavior include methods based on overactuation/oversensing [5] and inferential control [2]. In the latter case, the performance variables are not equal to sensed variables. A typical example involves the internal deformation of a stage, since the position measurement is performed at the edge of the stage, while performance should be achieved in a central position. Hence, the performance of the system has to be predicted by means of a model, since it cannot be measured. In this case, the performance of the system crucially depends on the quality of the underlying model. In this research, an approach to model-based control of multivariable flexible systems is investigated that can roughly be divided into three steps, see Figure 1.

Firstly, a novel approach that can deal with the experimental modeling of flexible multivariable systems is being developed, see [4] and [1]. The experimental modeling approach in [4] enables an inexpensive, fast, and accurate identification of flexible systems in view of subsequent compensation of the dominant flexible behavior. Specifically, a low-order multivariable model is obtained that emphasizes the control-relevant flexible dynamics.

Secondly, a model validation approach is being investigated, see [3]. Model validation amounts to testing the predictive power of the model using new data sets. Model validation 1) is an essential ingredient if the practical limit of compensating the flexible plant behavior is being determined; 2) is crucial if the performance of the

system is predicted, as is the case in inferential control; 3) enables a characterization of the obtained model quality by means of an uncertainty model.

Thirdly, optimal control of flexible multivariable systems is considered, extending the rigid-body approach in [6] to enable the control design for flexible systems. The control approach enables a direct multivariable control design, using the model from Step 1, while taking into account the model uncertainty of Step 2.

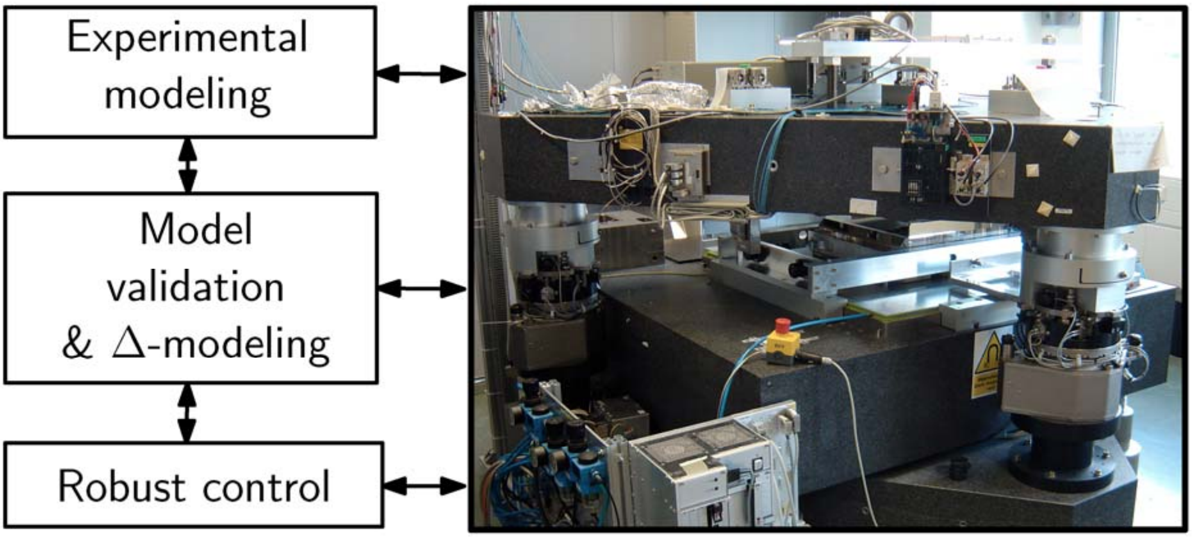

Fig. 1: Research approach.

First experimental results of the presented approach on a next-generation wafer stage, see Figure 1, reveal promising results. Concluding, a model-based approach is being investigated that aims at improving the present state-of-the-art tools, thereby enabling beyond-rigid-body control.

References

[1] D. S. M. Denie. Accuracy assessment in frequency response-based identification of a flexible mechatronic stage. Master's thesis, Eindhoven University of Technology, Eindhoven, The Netherlands, 2008. APT536-08-2396.

[2] J. Hong and D. S. Bernstein. Bode integral constraints, colocation, and spillover in active noise and vibration control. *IEEE Transactions on Control Systems Technology*, 6(1):111–120, 1998.

[3] T. Oomen and O. Bosgra. Estimating disturbances and model uncertainty in model validation for robust control. In *Proceedings of the 47th Conference on Decision and Control*, pages 5513-5518, Cancún, Mexico, 2008.

[4] T. Oomen and O. Bosgra. Robust-control-relevant coprime factor identification: A numerically reliable frequency domain approach. In *Proceedings of the 2008 American Control Conference*, pages 625–631, Seattle, Washington, United States, 2008.

[5] S. J. Schroeck, W. C. Messner, and R. J. McNab. On compensator design for linear time-invariant dual-input single-output systems. *IEEE Transactions on Mechatronics*, 6(1):50–57, 2001.

[6] M. van de Wal, G. van Baars, F. Sperling, and O. Bosgra. Multivariable H_∞/μ feedback control design for high-precision wafer stage motion. *Control Engineering Practice*, 10(7):739–755, 2002.