Robust Beyond-Rigid-Body Control of Next Generation Wafer Stages

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Background

Increasing throughput requirements in semiconductor manufacturing demand for higher accelerations in wafer stage motion. In virtue of Newton's law, higher accelerations can be achieved if stages are lightweight. Increasing performance requirements and lightweight stage design result in flexible dynamics in the controller crossover region [2]. The goal of the present research is to enable high performance motion control for next-generation flexible stages in the presence of flexible dynamics.

Control challenges

Flexible dynamics are typically not aligned with the motion degrees-of-freedom, resulting in an inherently multivariable plant. To enable the design of high performance controllers for such systems, model-based controller design is essential [1]. To connect experimental modeling and controller design of flexible mechanical systems, increased model complexity and accuracy is required compared to the present state-of-the-art. In addition, a classification of flexible dynamics that limit control performance and that do not affect control performance is required. These control-relevant flexible dynamics should explicitly be modeled and compensated to enable high performance motion.

Experimental results

A procedure consisting of experimental modeling, model validation, and robust control design has been developed and applied to a next-generation wafer stage. Firstly, a new basis for the choice of control relevant coprime factors $P = ND^{-1}$ has been developed, extending [3], see [4] and Fig. 1 for experimental results on a next-generation wafer stage. Clearly, the rigid-body behavior and the first resonance phenomena are control-relevant. Secondly, to confirm the extended model of the flexible behavior, model validation has been enhanced [5] to deal with both disturbances and model uncertainty in a control-relevant setting. The set of not invalidated candidate plant models is depicted in Fig. 2. Clearly, the control-relevant dynamics are modeled accurately. Finally, the optimal robust controller is depicted in Fig. 2, revealing that the worst-case performance is significantly improved and relevant resonance phenomena are explicitly compensated.

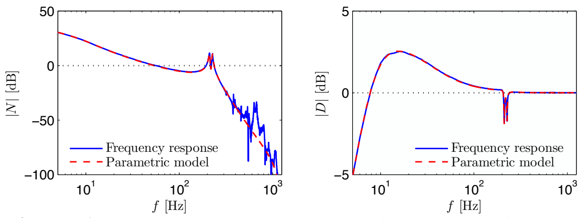

Figure 1: Control-relevant coprime factor identification.

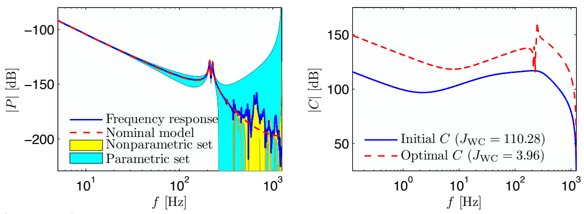

Figure 2: Left: not invalidated models, right: optimal controller.

Conclusions

A novel procedure has been presented that connects experimental modeling and robust control. Experimental results confirm improved accuracy of the extended model. In addition, the procedure enables a classification of resonance phenomena that are important to model and compensate and dynamics that are irrelevant.

References

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