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Thermal control in wafer scanners using high complexity models

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1 Introduction

The performance of ASML’s wafer scanners is mainly measured in terms of speed and resolution. The company is therefore aiming at reducing feature sizes on chips, while at the same time increasing machine throughput. As a result error margins become smaller, while both the power and bandwidth of signals increase.

Thermally induced deformations of various components are a significant source of errors in wafer scanners \cite{1} \cite{2}. In practice, low complexity models are used for real time control purposes, because high complexity models are generally not fast enough. These low complexity models have a limited accuracy, which therefore limits the system performance. For this reason the use of high resolution, multiphysics models for control purposes is proposed.

2 Modeling of heat transfer and thermal expansion

Thermal diffusion is described by a partial differential equation, which can be described by an infinite dimensional system. A finite dimensional approximation of these systems can be created using the finite elements method. For linear thermal expansion the thermally induced deformations $z$ can be modeled by a linear mapping of the temperature states $T$, which is described by $z = AT$. In order for these models to be accurate, generally $\gg 10^4$ states are required, which leads to slow and complex models. Because of this, these models are generally only used for simulation and analysis purposes \cite{3}.

3 Control based on low complexity models

Consider the system interconnection in Fig. 1. The plant is subject to disturbances $d$ (e.g. heat fluxes), has inputs $u$ (e.g. heater power set-points) and measured outputs $y$ (e.g. measured temperatures). The deformations $z$ cannot be measured continuously.

In general, low order lumped elements models are used in thermal control. These low order models describe thermal behavior relatively well, but lack the spatial resolution required to determine the resulting deformations $z$ accurately. For this reason the control objective is defined on $y$, which can be measured accurately \cite{3}. With this approach, some norm on the deformations $\|z\|$ is reduced by reducing $\|T\|$.

4 The advantage of high complexity models

High complexity models on the other hand are capable of accurately determining the deformations $z$ accordingly. Therefore, it is possible to reduce $\|z\| = \|AT\|$ directly. In this way the entire null space of $A$ can be utilized instead of just working towards the trivial solution $\|T\| = 0$. Moreover, in some cases it is desired to minimize a weighted norm of $z$. As a result, extra freedom in the control of the temperature states is introduced, which can be used to improve the controlled system performance.

5 Future Work

For control of thermally induced deformations, high complexity models can theoretically be used to increase the system performance. However, these models are generally not fast enough. Model reduction can be used to overcome this problem, but utilizing these reduced models for real time control is not trivial \cite{2}. As a first step, model reduction for this type of systems will therefore be investigated. The aim is to develop an accurate thermo-mechanical model that is $5 - 10$ times faster than real time.

References

\cite{2} C. Bikcorka, S. Weiland, and W. M. J. Coene, “Reduced-order modeling of thermally induced deformations on reticles for extreme ultraviolet lithography,” in American Control Conference (ACC), 2013, 2013, pp. 55425549.

\[ z = AT \]