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Decoupling of collocated actuator-sensor-pairs for active vibration control

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1 Introduction

High-precision machines typically suffer from small but persistent vibrations. As it is difficult to damp these vibrations by passive means, research at the Drebbel Institute is aimed at the development of an *active structural element* that can be used for vibration control. The active structural element, popularly referred to as 'Smart Disc', is based on a piezoelectric position actuator and a piezoelectric force sensor.

One of the main problems in active control is to ensure stability. In this respect it is often advantageous to consider the use of so-called *collocated* actuator-sensor-pairs, as this enables to actively implement a passive control law, which is robustly stable, irrespective of structural modeling errors. Within the context of vibration control for lightly damped structures, collocated actuator-sensor-pairs are known to be well-suited to obtain robust active damping [1, 2].

2 Example: wafer stepper lens vibrations

A wafer stepper, i.e., the advanced microlithography system that is at the heart of Integrated Circuit manufacturing, is an excellent example of a high-precision machine the performance of which is limited by the lack of damping within the machine frame. Badly damped vibrations of the lens of the wafer stepper limit the attainable line width of the circuit patterns.

The lens of the wafer stepper is conventionally suspended by means of three (passive) lens support blocks, constituting a kinematically well-designed interface to the so-called metroframe of the wafer stepper. In order to perform Smart Disc experiments, the lens support blocks have been equipped with two piezoelectric stacks, both comprising a position actuator and a collocated force sensor. Each of the resulting 'Piezo Active Lens Mounts' has two perpendicular active degrees of freedom.

By applying collocated control to the individual piezoelectric stacks, all six 'suspension modes' of the lens can be damped. Due to the passivity of the control laws, unmodeled flexible modes of the lens and the metroframe are also stabilized.

3 Collocated control versus modal analysis

Control based on collocated actuator-sensor-pairs is inherently in terms of *local* coordinates. Vibration problems however are usually analyzed in terms of *modal* coordinates, corresponding to a limited number of vibration modes, as captured in a simplified model of the mechanical structure.

In terms of the wafer stepper example: we are primarily interested in the six suspension modes of the lens. From a modal analysis point of view, it is therefore desirable to have six SISO control problems, each one directly related to a single suspension mode. However, due to the symmetry in the set-up, the frequency response functions from a single actuator to the collocated sensor are all similar. Tuning of the local control laws, such that damping for the individual modes is optimal, is therefore not straightforward.

4 Modal control through decoupling

The above-mentioned problem can be solved by realizing that decoupling of collocated actuator-sensor-pairs, i.e, the transformation of the original control problem into modal coordinates, yields control loops that again enable the implementation of a passive control law. Stability of 'decoupled collocated control' does not depend on the accuracy of the model that has been used for decoupling.

This implies that, for the case of the wafer stepper, a simple 'rigid-body' model may be used for decoupling of the six collocated control loops. Obviously, in contrast to stability, the *performance* of active damping based on 'decoupled collocated control' *does* depend on the accuracy of the model.

References

[1] S.M. Joshi, "Control of Large Flexible Space Structures", Lecture Notes in Control and Information Sciences, Vol.131, Springer-Velag, Berlin, Germany, 1989.

[2] A. Preumont, "Vibration Control of Active Structures, An Introduction", Kluwer Academic Publishers, Dordrecht, The Netherlands, 1997.