Modelling of a nanometer-accurate planar actuation system

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Modelling of a nanometer-accurate planar actuation system

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1 Introduction

In our modern society there is an ever increasing need for higher computational power and storage capacities together with a reduction at the production costs. In the semiconductor industry, the effort to achieve these demands involves the increase of the wafer sizes and circuit detail, together with high throughput speed. The transition from dual-stage positioning systems [1] to a magnetically levitated planar actuator is one of the qualified solutions towards new, high-end lithographic machines.

A moving-coil magnetic levitation system has been recently manufactured in the semiconductor industry for high-end production. Its simple design partially facilitates the control architecture but it may require a combination of long and short stroke due to disturbances such as the ones induced by the cable slack on the moving coil. At the Eindhoven University of Technology a reversed construction based on a moving-magnet prototype was designed and realized in the recent years. The main goal is to investigate the possible benefits and limitations of this setup by deploying a control architecture tailored for this system.

2 Description and modelling of planar motor system

The planar motor system comprises three distinct parts, as shown in Figure 1. These are the coil bed which rests on a solid, heavy base and it is enclosed by the metrology frame, which rests on four air mounts which passively reject any disturbances induced by the ground. Finally, the magnetic plate is allowed to float on top of the coil bed area and its position is reconstructed using 3 triplets of interferometers (IFM), targeting at the x, y and z axis.

![Figure 1: Schematic of the NAPAS actuator](image)

By aiming at a model-based control approach, the first essential step is the modelling of the underlying dynamics, which mainly involve the electromagnetic relations that describe the coil-magnet interaction, as well as the mechanical equations that describe the six degrees-of-freedom (DOF) motion of the translator. Under the rigid body assumption, the motion dynamics exhibit a position-dependent nature, as shown in the equivalent state-space representation:

\[
\begin{align*}
\dot{\mathbf{q}} &= \begin{bmatrix} M^{-1}(q) C_1(q,\dot{q}) & 0 \\ I_{3\times3} & 0 \end{bmatrix} \begin{bmatrix} \dot{q} \\ q \end{bmatrix} + \begin{bmatrix} M^{-1}(q) \psi(q) \\ 0_{6\times3} \end{bmatrix}
\end{align*}
\]

where \( q = [x_s \ y_s \ z_s \ \chi_s \ \psi_s \ \zeta_s]^{\top} \) and \( x_s, y_s \) and \( z_s \) denote the position of the Center of Mass (CoM) of the translator, while \( \chi_s, \psi_s, \zeta_s \) denote the rotation around the axes of the metrology reference frame. Moreover, \( W \) represents the force and torque and \( M, C_1, C \) and \( J \) are nonlinear functions with respect to the six DOF.

3 Modelling of spatial dynamics

Following the development of a position-dependent state-space model under the rigid body assumption, the goal is the incorporation of spatial dynamics in the model. Due to the limited-stiffness of the magnetic plate, flexible dynamics may pose a restriction towards stricter performance specifications. To this end, a Finite Element Method (FEM) model is currently under development. Nonetheless, manufacturing tolerances may lead to inaccurate modelling of the flexible dynamics, which can in turn lead to unstable behaviour of the controlled closed-loop system. For this reason, the completion of the FEM model using system identification techniques will be pursued.

Finally, the last step involves the combination of the analytic rigid body model with the FEM based flexible dynamics model, aiming at deriving an accurate and complete description of the mechanical dynamics, which will facilitate the design of high performance controllers for nano-meter accuracy under high accelerations.

References