Optimal high-bandwidth non-collocated control of ball-screw drives

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Abstract

This work presents a novel optimal control strategy for precision motion control of flexible ball-screw feed drives. Typically, ball-screw feed drive control relies on state feedback taken both from motor and the load sides. The controller designed in this thesis is based on the non-collocated framework, where all the feedback measurements are taken from table (load) side for cost savings and higher performance. A high-speed ball-screw driven motion stage is designed and prototyped as a test-bed for controller development. Physics based lumped-mass model of the system is identified based on frequency response analysis. The parametric model is utilized in non-collocated controller design. Table (load) acceleration and jerk feedback measurements are incorporated to independently control rigid body and structural dynamics of the system. Linear quadratic regulator (LQR) framework is employed for optimal pole placement. State based LQR weights are mapped to frequency domain performance targets, i.e. crossover frequency and phase margin, and hence a novel frequency domain optimal tuning strategy is achieved. A kinematic state observer design is also presented to fuse analog accelerometer measurements with linear encoder feedback to realize high-fidelity state feedback and robust wide-bandwidth motion control. Robustness analysis of non-collocated control is carried out, and comparison against conventional full closed loop collocated controllers is given. Finally, comprehensive experimental validations and performance benchmarks are undertaken to validate controller effectiveness.

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