Active and Passive Control of Machine Tool Vibrations for High Speed and Accuracy

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Abstract

High-performance mechatronic systems are widely used in precision manufacturing equipment such as CNC machine tools, 3D-Printers, photolithography systems, and industrial robots. To keep up with the rapidly increasing productivity and accuracy demands, it is crucial that mechatronic systems (feed drives) of these manufacturing equipment deliver high-speed motion with high precision. In this dissertation, motion control strategies are presented to increase dynamic positioning accuracy and productivity of such systems. First, a novel trajectory generation method is presented to avoid exciting low frequency structural vibration modes, without compromising from productivity. Trajectory generation problem is posed as a convex optimization problem, and a practical windowing method is presented to implement the proposed strategy in real-time for realistic manufacturing scenarios. Next, a data-driven trajectory shaping algorithm is designed to eliminate dynamic positioning errors induced by flexible motion transmission components (such as ball screw drives) and nonlinear friction forces typically caused by mechanical bearings and guiding units. The proposed algorithm is used for optimizing trajectory pre-filters through machine-in-the-loop iterations, and therefore it can be applied on a wide variety of systems without elaborate dynamic modeling. Finally, an active tool position control strategy is proposed to mitigate chatter vibrations for improving stability margins of turning processes. Two motion control algorithms are developed to control the dynamic interaction between the tool and the workpiece. Effectiveness of the proposed strategies is demonstrated on machine tools by high-speed tracking and machining experiments.

Thursday, March 18th, 2021

10am, Zoom Meeting

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