Model order reduction via substructuring for a nonlinear, switched, differential-algebraic machine tool model

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Machine tools are permanently exposed to complex loads, induced by static, dynamic and thermal effects. This often results in an undesired displacement of the tool center point (TCP), causing additional errors in the production process and thus limiting the achievable workpiece quality. To counter these effects, profound knowledge in modeling and simulation techniques is required. Also, current research impulses in the context of model-based data analytics strive for process-parallel solutions utilizing machine internal data.

In order to combine existing modeling capabilities with modern data-driven approaches, a massive reduction of calculation times is a fundamental requirement. At this point, model order reduction (MOR) becomes crucial. Sophisticated MOR strategies enable the computation of compact low-dimensional models for the fast simulation of entire machine tool models while preserving the model accuracy. The resulting low-dimensional models are required for various applications, e.g., in digital twins, the correction of thermally induced errors at the TCP during the production process as well as for lifetime calculations in predictive maintenance.

In this contribution, we investigate advanced modeling of thermo-mechanical effects in machine tools with nonlinear machine components using the example of a feed axis. We present strategies of MOR for this coupled thermo-mechanical model with nonlinear subsystem and moving loads. Applying tailored substructuring techniques, we are able to separate the linear and nonlinear system components. This allows to apply classic linear MOR methods, to the, in our case much larger, linear parts, and thus enables drastically reduced computing times. Transient thermo-mechanical interactions of the feed axis are calculated in a final investigation, comparing the performance of the resulting reduced-order model and the original one.