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Black-Box-Optimization Approach for High Precision Multi-Axes Forward-Feed Design

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Abstract : A new method for optimal selection of components for multi-axes forward-feed drive systems is proposed in which the choice of motors, gear boxes and ball screw drives is optimized. Essential is here the synchronization of electrical and mechanical frequency behavior of all axes because even advanced controls (like H∞-controls) can only control a small part of the mechanical modes – namely only those of observable and controllable states whose value can be derived from the positions of extern linear length measurement systems and/or rotary encoders on the motor or gear box shafts. Further problems are the unknown processing forces like cutting forces in machine tools during normal operation which make the estimation and control via an observer even more difficult. To start with, the open source Modelica Feed Drive Library which was developed at the Laboratory for Machine Tools, and Production Engineering (WZL) is extended from one axis design to the multi axes design. It is capable to simulate the mechanical, electrical and thermal behavior of permanent magnet synchronous machines with inverters, different gear boxes and ball screw drives in a mechanical system. To keep the calculation time down analytical equations are used for field and torque producing equivalent circuit, heat dissipation and mechanical torque at the shaft. As a first step, a small machine tool with a working area of 635 x 315 x 420 mm is taken apart, and the mechanical transfer behavior is measured with an impulse hammer and acceleration sensors. With the frequency transfer functions, a mechanical finite element model is built up which is reduced with substructure coupling to a mass-damper system which models the most important modes of the axes. The model is modelled with Modelica Feed Drive Library and validated by further relative measurements between machine table and spindle holder with a piezo actor and acceleration sensors. In a next step, the choice of possible components in motor catalogues is limited by derived analytical formulas which are based on well-known metrics to gain effective power and torque of the components. The simulation in Modelica is run with different permanent magnet synchronous motors, gear boxes and ball screw drives from different suppliers. To speed up the optimization different black-box optimization methods (Surrogate-based, gradient-based and evolutionary) are tested on the case. The objective that was chosen is to minimize the integral of the deviations if a step is given on the position controls of the different axes. Small values are good measures for a high dynamic axes. In each iteration (evaluation of one set of components) the control variables are adjusted automatically to have an overshoot less than 1%. It is obtained that the order of the components in optimization problem has a deep impact on the speed of the black-box optimization. An approach to do efficient black-box optimization for multi-axes design is presented in the last part. The authors would like to thank the German Research Foundation DFG for financial support of the project “Optimierung des mechatronischen Entwurfs von mehrachsigen Antriebssystemen (HE 5386/14-1 | 6954/4-1)” (English: Optimization of the Mechatronic Design of Multi-Axes Drive Systems).

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