Available online at www.sciencedirect.com
ScienceDirect
IFAC Papers Online CONFERENCE PAPER ARCHIVE
IFAC-PapersOnLine 48-1 (2015) 268–273

Design of Feed Drives with Object-Oriented Behavior Models

W. Herfs, D. Özdemir, W. Lohse, C. Brecher

Laboratory for Machine Tools and Production Engineering (WZL) of the RWTH Aachen University Aachen, Germany (e-mail: {w.herfs, d.oezdemir, w.lohse, c.brecher}@wzl.rwth-aachen.de)

Abstract: Feed drives are designed with manual calculations, custom spreadsheets or with special sizing software. Manual calculations and spreadsheets are based on simplified calculations and are generally time-consuming. Software packages for sizing servo systems provide effective means for many standard applications, but also have several limitations: they do not allow application-specific extensions, detailed analysis of control loops dynamics in the time and frequency domain is not possible, and they therefore cannot be used for optimizing the system as a whole. In this paper an alternative approach for sizing servo systems is presented that enables analysis and optimization of the system dynamics. The approach relies on object-orientated behavior models. These models are included in an extensible model library that facilitates quick model development even with limited expert-knowledge in simulation. For supporting the determination of parameters and components the simulation-framework is combined with methods that allow optimization of discrete and continuous parameters.

Keywords: Feed drives, Modelling, Optimization, Modelica

1. INTRODUCTION

Feed drives have major influence on the performance, reliability and cost of machine tools and production plants. Oversized components lead to high costs, not only with regards to purchase, but more importantly with regards to energy consumption over the lifecycle. With undersized components the machine will not be able to meet performance or reliability requirements. Moreover, feed drive components have to be chosen with regards to their dynamic properties to account for size tolerances of the work piece.

Feed drive design has been considered since the 1960s when numerical control (NC) and motion control (MC) were introduced. In the 1970s first computer programs have been developed for the selection of motors from databases and for the design of mechanical transmission elements (Wolters, 1976; Böbel, 1979). With the fast progress of microelectronics in the 1980s new drive concepts with much faster dynamics became available. In that course the motor no longer was the only component to limit motion dynamics, but also the mechanical transmission elements and their eigenfrequencies had to be considered. Therefore models of drives and multi-mass systems have been coupled to consider vibrations of transmission elements (Simon, 1986). In the subsequent years simulation became increasingly common in the area of feed drives. Research topics that started in the 1990s, but are still relevant today, include coupled simulation of structural dynamics and control loops, integrated simulation of machine and process and physical NC-path simulation (Altintas et al., 2005; Brecher et al., 2009). These advances help to analyze and test machines virtually in the late design stage and during start-up. However, the problem of quickly comparing different feed drive design concepts and choosing adequate components remains largely unsolved.

The approach that is presented in this paper aims to close this gap by leveraging object-oriented physical modelling languages in combination with optimization techniques for parameter and component determination. The paper is structured as follows. The next section summarizes the feed drive design process. Section 3 comprises the new design concept by describing the combination of object-orientation models and optimization techniques. Section 4 outlines the employed behavior models and section 5 the required data. Section 6 discusses different optimization techniques for the behavior models. Subsequently, the approach is applied to a uses case in section 7.

2. FEED DRIVE DESIGN PROCESS

Depending on the application-specific requirements – including power, force, speed, acceleration, precision and costs – different types of feed drives are considered and typically more than one type is potentially applicable. Machine tool axes, for example, can be equipped with a rotary motor in combination with a ball-screw or a rack-pinion system. Alternatively the translational motion can be generated directly by a linear motor. Advantages and disadvantages of each configuration have been studied in detail (Altintas et al., 2011).

Fig. 1 depicts the structure of a ball-screw system, which is a typical example for a feed drive. Starting from the synchronous motor the torque is applied to the spindle via a belt drive. The rotation of the spindle is transferred into translation of the table depending on the pitch. The position of the table is detected with a linear encoder and the values are then compared to the set values from the NC kernel. A cascaded structure with

Peer review under responsibility of International Federation of Automatic Control.
10.1016/j.ifacol.2015.05.022

position, speed and current control loop follows. Coordinate transformation and pulse width modulation are necessary to generate three phase current from the virtual value of torque-building current.

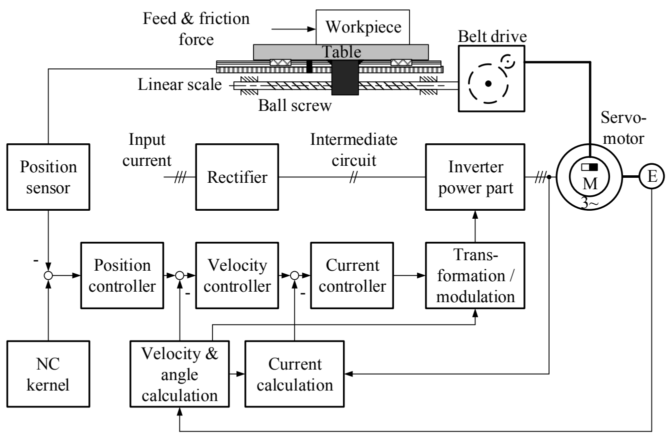

Fig. 1: Simplified structure of a feed drive with ball-screw

For a structure, as depicted in Fig. 1, several design and parameter choices have to be made, e.g. servomotor, inverter, belt drive or clutch, ball screw, measurement system, controller and controller parameters. Making optimal choices with regards to the requirements of dynamics, precision and costs is a difficult task since the choices depend on each other. For example a smaller pitch of the spindle will require higher spindle speed for the same velocity of the table. Accordingly, a different combination of belt drive and motor may then be more suitable. All of the components can have significant impact on the overall performance. A heavy and rigid clutch, for example, can lead to instability within in the speed control loop caused by the roots and poles of the frequency response in the area of the characteristic frequency of the drive (Gross et al., 2006).

The interdependencies lead to several iteration loops within the feed drive design process (Weck & Brecher, 2006). Usually the design process starts from an initial selection of components without specifying the motor. A pre-selection of the motor is made by calculating maximum torque, rotational speed and power on the drive end. Next, the acceleration time to desired speed is computed knowing inertia of motor and load. Assuming a motion profile or a sequence of machining operations that the feed drive should handle, the effective torque is calculated by taking the weighted root mean square. Motor suppliers typically provide a S1-curve, which comprises the area in the torque-speed characteristic where the motor does not exceed a certain overtemperature. The effective torque is compared to the S1-curve within the torque-speed characteristic. If the motor does not meet the requirements a different spindle, gear ratio or motor is chosen and the process starts again. After the motor is specified, the inverter is chosen with regards to the effective and maximum current. Loads on the mechanical elements are calculated to validate load limits, life expectancies, etc. Finally, frequency responses of the controlled system and the closed control loop can be simulated to validate the dynamic behavior of the feed drive.

Several tools are offered to support the described process, e.g. Sizer for Siemens drives, Motion Analyzer from Rockwell Automation or the supplier independent software Servosoft by ControlEng. While these sizing tools are a helpful and easy-to-use means for many standard applications, we see several shortcomings. First, the tools only allow modelling in the range of pre-defined configurations. For example, it is not possible to include an application-specific friction model. Second, the tools do not include frequency analysis. This may lead to a choice of inappropriate components. Third, the design process followed by the tools is sequential, i.e. components and parameters are chosen one after the other. However, an overall optimal parameterization requires simultaneous consideration of all parameters.

3. CONCEPT OF FEED DRIVE DESIGN WITH COMPONENT-ORIENTED BEHAVIOR MODELS

The concept presented here aims to overcome the shortcomings of existing sizing tools with regards to extensibility, frequency analysis and parameter optimization. It consists of four parts:

1. Extensible object-oriented models that allow both, stationary and dynamic analysis
2. Design requirements for feed drive systems
3. Database with component-data
4. Optimization algorithms that search for parameters and components that optimally satisfy the design requirements

Fig. 2 shows the interaction between the four parts in the optimization environment. Basis for optimization are the component-oriented behavior models of the feed-drive system. These models are augmented by design requirements formulated as objectives and constraints. The corresponding variables are passed to the optimizer. The optimizer aims to select parameters and components that improve requirement satisfaction in the subsequent iteration. If gradients and Hessian matrices can be provided by the modeling and simulation environment, these can be used by the optimizer to obtain faster and more robust convergence. Depending on the problem specification, each degree of freedom of the optimization problem can either be a single parameter or a parameter vector that corresponds to a specific component, e.g. a motor or ball-screw-drive. In the first case, the optimization environment parameterizes the simulation model with individual values. In the second case, the optimization algorithm selects components from a database and the model is then parameterized from the database.

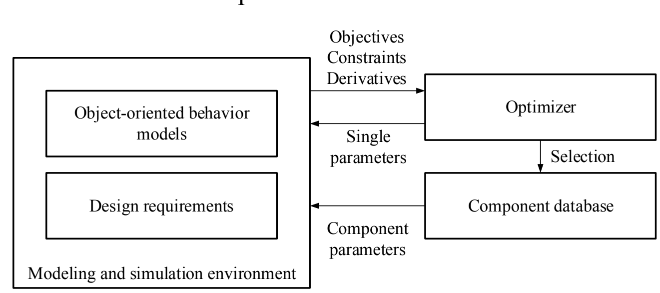

Fig. 2. Optimization environment