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Modeling and active damping of structural vibrations in machine tools

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ABSTRACT

The positioning accuracy of the high speed machine tools is determined by the bandwidth of servo controllers, which is mainly limited by the structural vibrations that are transmitted to the control loop. This paper presents modeling of machine tool structures and their active damping in the feed drive control loop. The fundamental modes of the machine tool structure that affect the controller are identified. A high bandwidth, sliding mode controller is simulated and experimented on a machine with and without active damping. It is shown that the vibrations can be actively damped, and the bandwidth of the drive can be increased.

Introduction

Machine tools exhibit structural flexibilities which are excited during high speed positioning of the drives [1]. Large components (i.e. column, tool changer and spindle housing) contribute to low Eigen-frequencies, while higher frequency modes originate from lighter components (i.e. tool and spindle). While metal cutting loads often have high frequencies and excite lighter parts of the machine, the inertial forces generated through acceleration and decelerations excite larger parts of high speed machine tools. If the inertial vibrations are felt by the control loop through encoder readings, the servo drive can be unstable and vibrate at the same frequency of structural modes. In general, there are three approaches to avoid the inertial vibrations.

The vibrations are notch filtered to prevent their transmission to control loop and the bandwidth of the drive servo is reduced. This classical approach reduces the high speed contouring ability of the machine, because the lowering of the bandwidth leads to increased axis tracking errors that are proportional to contouring feed speeds [1].

Alternatively, the position commands can be pre-shaped to avoid the excitation of natural modes of the machine [2]. However, input shaping brings phase delay to axis commands which lead to severe distortion of the tool paths in multi-axis operations. Altintas and Khoshdarregi presented a combination of input shaping and feed-forward contouring error compensation by predicting the tracking errors of drives ahead of sending position commands to drives [3].

It is more common to damp the natural vibrations through active damping network within the servo control loop. If the frequency of the vibration is beyond the bandwidth of the drive, external actuators dedicated to damping are added to the system [4–6]. However, such measures increase the complexity and the cost of the machine tool. It is more ideal to use the existing servo motor and sensors of the drive to actively damp the vibrations. Since the encoders may not have enough resolution, Pritschow et al. [7] used Ferrari sensor to damp the vibrations by using acceloremetric feedback. Erkorkmaz and Kamalzadeh [8] and Okwudire and Altintas [9] proposed nonlinear, robust sliding mode controller of feed drive to actively damp the natural vibrations of ball screws. Tuning of the sliding mode controller becomes quite cumbersome when the structural modes of the drive are included. It is preferred to design a simple to design and tune active damping network, which is the focus of this article.

This paper presents modeling, identification and active damping of low frequency machine tool modes for CNC feed drives. The fundamental modes of the machine tool column and ball screw drive are modeled, and the relative transfer function between the table and guide is developed analytically. The parameters of the transfer function are estimated from experimental excitation of servo motor and linear encoder output directly. It is shown that typically bending and torsional modes of the machine tool column structure, as well as the axial vibration mode of the ball screw interferes with the servo controller most. The experiments and simulations show that the controller becomes highly oscillatory

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