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Design and control of a dual-stage feed drive

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Abstract

High precision positioning over a large workspace is a fundamental feature of a precision machine. Connecting coarse (large stroke) and fine (high resolution) drive stages, in series, to form a dual-stage feed drive (DSFD) system can provide the desired performance. The DSFD concept has applications that include fast tool servos for the creation of asymmetric surfaces or online chatter suppression, and micro–macro robots for high precision assembly. This paper studies the design of DSFDs for machine tools. The design issues are discussed with special considerations for the dynamics and control of the two drive stages. Two DSFDs, single-axis and two-axis, are designed with piezoelectric actuators (PAs) for the fine stages and linear motors (LMs) for the coarse stages. Both feature flexures for frictionless precision motion that are designed to meet the static and dynamic requirements of a milling process. A model-based control algorithm ensures that the stages work together in a complementary fashion. The single-axis DSFD reduced the tracking error by about 75% in comparison to a similarly controlled LM drive. A second DSFD was built for milling experiments. In sinusoidal profile cutting the maximum tracking error was reduced by 83% and the average magnitude of the error was reduced by 63%. In sharp corner cutting the DSFD reduced the maximum tracking error by 38% and the average magnitude of the error by 39%.

Keywords: Digital control; Dual-stage; Feed drives; Finite element analysis; Linear motors; Model-based control; Machine tools; Piezoelectric actuators

1. Introduction

High precision positioning is one of the most important features of a precision machine [1]. Such a machine is required to provide versatility, speed and workspace as well as high precision positioning. Combining coarse (large stroke) and fine (high resolution) drive stages, connected in series, to create a dual-stage feed drive (DSFD) provides the capacity of a large workspace with the property of high precision motion [2].

The DSFD concept has several applications in manufacturing, robotics and data storage. The majority of DSFD applications are in hard disks. The industry continues to strive for increased storage densities and reduced data access times. This necessitates performance improvements of the head positioning system in terms of fast transition from one track to another (track seeking), fast and accurate settling, and precise track following of the target track. To meet these requirements, the servo bandwidth of the head positioning system must be increased to lower the sensitivity to disturbances such as disk flutter vibrations, spindle motor run-out, windage, and external vibration. The servo bandwidth, however, is mainly limited by the mechanical resonance of the head positioning mechanism. Several DSFDs have been developed that can increase the servo bandwidth [3–7].

Micro–macro robots are another example of DSFDs that provide advantages when both large work space and precise end-effector positioning are required [8]. The parallel coupled micro–macro robot system, described in Ref. [9], exhibits superior characteristics when compared to typical single actuator robot systems. The benefits of this system are improved small signal force control bandwidth, reduced impedance, reduced distortion, reduced impact forces, improved small signal position bandwidth, improved force resolution and dynamic range.

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