Influences of Control, Feedback and Servo Drive Systems on Precision Machining

C. Brecher, D. Lindemann, C. Wenzel
Fraunhofer Institute for Production Technology IPT, Germany

dominik.lindemann@ipt.fraunhofer.de

Abstract

The mechanical design of ultra precision machine tools is very well experienced today. In contrast to that, the design and implementation of closed loop controls for high precision applications have not been sufficiently analyzed yet. In addition to that, enhancements to further increase the achievable form accuracy and surface quality and at the same time decrease cycle times and error sensitivity of precision processes can only be accomplished by enhancing the machine control. At the Fraunhofer IPT a test bench has been developed to analyze machine controls, servo drives as well as encoder and sensor systems with regard to an evaluation of capabilities of their application in ultra precision machines. First analyses have been accomplished focusing on the performance of servo drives, which will be presented in this paper.

1 Introduction

To establish a platform for the detailed analysis of all components involved in the control loop of a precision axis, an ultra precision test bench has been developed at the Fraunhofer IPT. Investigating on all components applied in closed loop controls, their individual performance and simultaneously mutual disturbances and limitations within the whole system can be identified. Focusing on hardware structures, software modules and data processing structures, an overall statement concerning all aspects of modern closed loop control systems can be elaborated. Due to the importance of fast controls for highly accurate axes, the research work focuses on analyzing servo drive systems. Many aspects such as the hardware structure of the drive, control cycle times or DC bus voltage have been taken into consideration to compare available servo drives and their performance on an ultra precision air bearing axis.

2 Test bench setup to analyze the influences of control components

The test bench has been configured as an ultra precision lathe to later validate the measured results by diamond turning an optical part. The setup uses two air bearing ironless linear drives and an air bearing spindle. A modular mounting grid allows for the flexible integration of external metrology such as laserinterferometers, laservibrometers or acceleration sensors. Thus, a complete investigation on all aspects of precision motion control can be guaranteed. Figure 1 shows the final test bench setup as well as the integrated metrology.

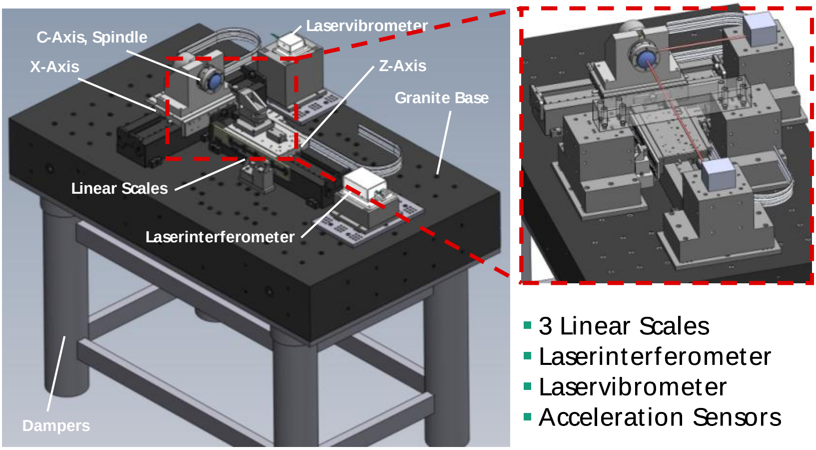

Figure 1: Test bench setup with integrated metrology

3 Influences of servo controls on the performance of precision axes

Common drive hardware architectures have been analyzed, involving the drive structure (analog or digital), the control strategy (PID-control or cascade circuits) and possibilities of decentralization (closing the loop in the drive or in a overlaying control). Aspects of cycle times, control clocks, DC bus voltage, different PWM frequencies and types of feedback signals have also been taken into account to completely determine the performance of available servo drives. The analysis focuses on two major requirements on an precision drive, the achievable axis stiffness and the precision of positioning including absolute accuracy and repeatability.

A comparison of different servo drives under the additional variation of control parameters has been accomplished. Figure 2 shows the influence of the hardware structure (linear or switching amplifier), of the PWM frequency (16 kHz or 100 kHz) and of the DC bus voltage (60 V or 350 V) on the lateral stiffness of an linear air bearing axis driven by an ironless linear motor. For higher frequencies the performances of the analyzed drives show similar behavior, but for low frequencies i.e. the static compliance a significant variation could be detected. A digital servo drive with high PWM frequency exceeds the performance of analog amplifiers, drives with lower PWM show a worse performance. Furthermore, the DC bus voltage has a strong impact on the stiffness (factor of ten measured with the same drive).

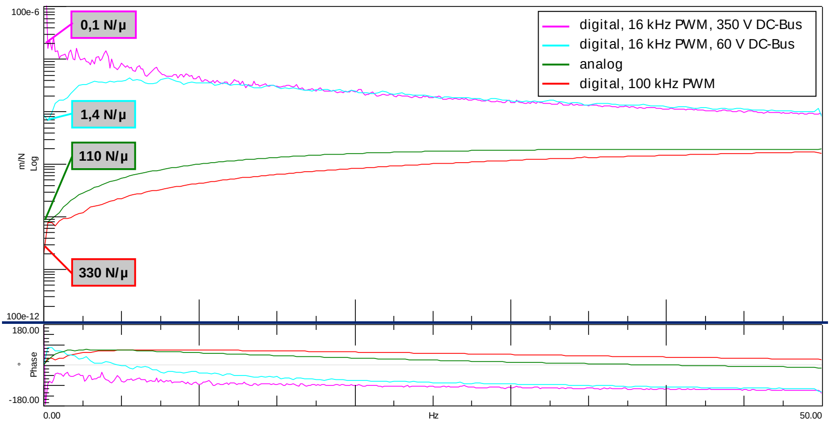

Figure 2: Influence of servo drives on the static stiffness of an air bearing axis

Besides the axis stiffness, the position accuracy of an axis system plays a key role for precision processes. To investigate on the position accuracy of different servo drives, a step response measurement has been carried out on the test bench. Ten steps with an increment of 10 nm have been given as setpoints for a switching amplifier and an analog servo control. Figure 3 shows the executed motion steps of the two drives measured with an external laserinterferometer. Looking at the position noise at standstill (Figure 3, top), the linear amplifier shows a lower noise (factor of two) within the range of plus/minus 3 nm. Even though the performance of the analog drive at standstill is better, the position accuracy (reaching the commanded absolute position exactly) of the digital drive is higher (Figure 3, bottom). Additionally, the switching amplifier keeps its position at each step (lower drift, Figure 3, bottom) more exactly, which corresponds to the higher achievable stiffness.

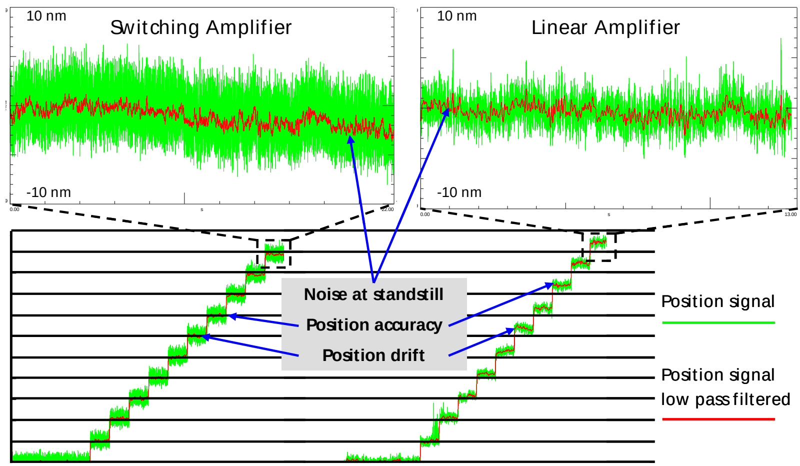

Figure 3: Influence of servo drives on the position accuracy of an linear axis

4 Conclusions and Outlook

At the Fraunhofer IPT a test bench has been developed and implemented to investigate on the influences of control components on the performance of precision axis. The first analyses accomplished have focused on the investigation of servo drives, taking the hardware structure and various control parameters into account. First result confirm that digital servo drives with high PWM frequencies can reach or even exceed the performance of linear amplifiers.

Future work will focus on the detailed analysis of linear scales with regard to encoder pitch, data signal, interpolation and sampling frequency as well as on various aspects of CNC controls such as NC cycle time, interpolation frequency and method or setpoint communication strategy. Not only the individual performance of the components, but also the mutual interaction within the control loop will be determined.