Analysis of Mutual Influences of Control, Feedback and Servo Drive Systems for Ultra Precision Machining

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Abstract

The mechanical design of ultra-precision machine tools is very well understood today. Detailed investigations on precision axes designs, dimensioning of bearings and drives and overall machine concepts have built a broad basis for designing very stiff and accurate state-of-the-art machine tools. Enhancements to further increase the achievable form accuracy and surface quality and at the same time decrease cycle times and error sensitivity can only be accomplished by innovative control and drive systems. In contrast to mechanical machine design, control, servo drive and feedback as well as their interactional behavior within a complex machine setup have not been sufficiently analyzed yet. This applies especially to ultra-precision machining. At Fraunhofer IPT a test bench has been developed to analyze machine controls, servo drives and encoder and sensor systems with regard to an evaluation of capabilities of their application in an ultra-precision lathe. This paper will give a summary of the results of servo drive and linear encoder analysis including both a comparison of individual components and an investigation on mutual interactions.

1 Introduction – Test environment to analyze precision control systems

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. A 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 laser interferometers, laser vibrometers or acceleration sensors.

Thus, a complete investigation on all aspects of precision motion control can be guaranteed. The test bench setup, shown in Figure 1, has been presented in detail at the 11th euspen International Conference 2011 in Como [1].

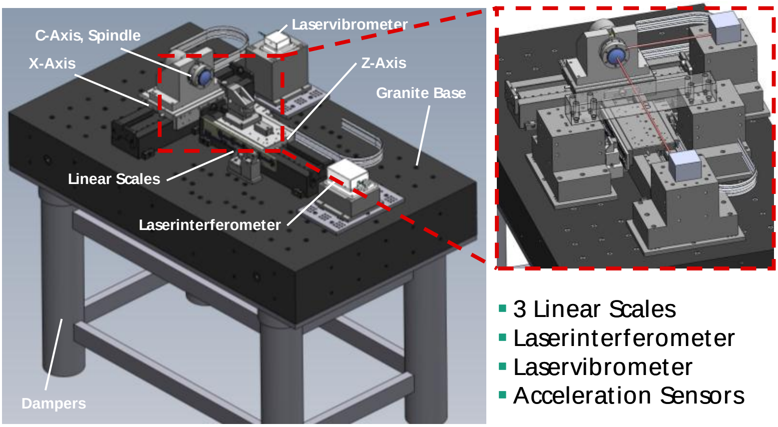

Figure 1: Test bench set-up with integrated metrology

The performed measurements include the analysis of the position accuracy and repeatability (step response) as well as the determination of the dynamic frequency characteristics (stiffness/ compliance) of an air bearing axis. With respect to the aforementioned measurements the tests have been performed under the variation of linear scales (vendor, pitch, signal, sampling frequency, etc.) and servo drives (vendor, switching or linear amplifiers, PWM (Pulse-Width Modulation) frequency, control architecture, DC bus voltage, etc.). First results have been presented at the 12th euspen International Conference 2011 in Stockholm [2].

2 Comparison of linear scales

As one aspect of the linear scale analysis an axis stiffness measurement has been performed. Under variation of scale pitch (between 250 nm and 20 µm) the air bearing axis has been excited with a piezo actuator with 40 N and a white noise signal. The position deviation has been measured with a capacitive sensor. The signal has been evaluated under statistic repetition to create a plot of the axis frequency behavior. Figure 2 shows the results at 4 kHz (dynamic behavior) and 40 Hz (static behavior). It can be seen that neither the dynamic nor the static stiffness shows significant dependence on the encoder pitch distance.

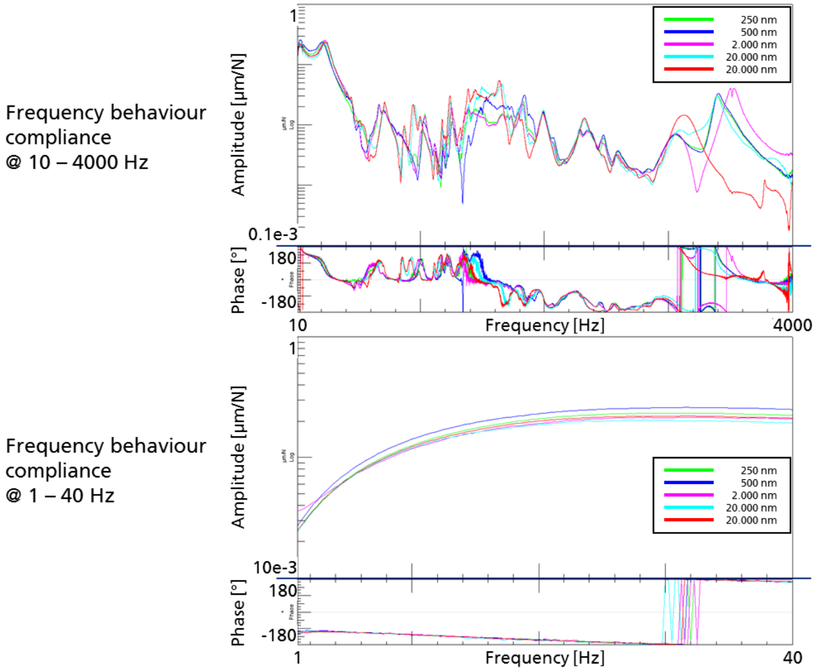

Figure 2: Comparison of scales – axis stiffness at 4 kHz / 40 Hz (variation of pitch)

3 Comparison of servo drives

Regarding the servo drive system comparison a step response test (10 steps, width between 10 nm and 10 µm) has been performed to analyze the position accuracy at standstill and in motion as well as the repeatability. Servo drives have been analyzed with respect to the PWM frequency and the comparison between linear and switching amplifiers. Figure 3 shows the results of the 20 nm and the 10 nm measurements and draws a comparison between a switching amplifier (8 kHz PWM) and a linear amplifier as well as a comparison between two switching amplifiers (16 kHz and 100 kHz PWM). The standstill noise of the linear amplifier achieves the best results (about 2 nm), but switching amplifiers with high PWM frequency nearly reach the same performance. The higher the PWM frequency, the better the position accuracy.

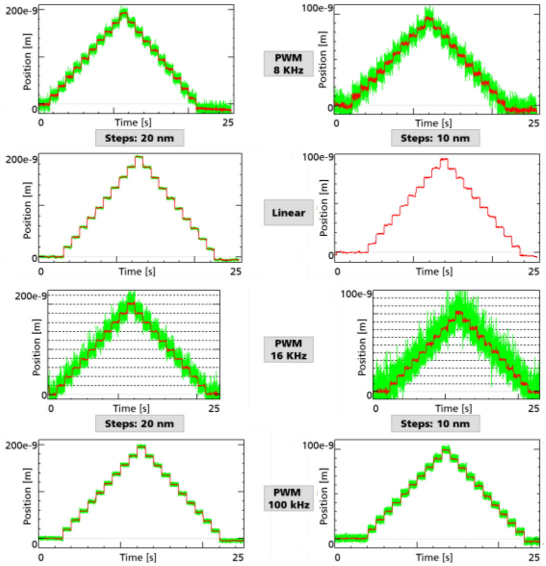

Figure 3: Comparison of drives – position accuracy (variation of topology / PWM)

4 Conclusions and Outlook

At the Fraunhofer IPT a test bench has been developed and setup to investigate on the influences of control components on the performance of ultra-precision axis. First results confirm that axis stiffness does not depend on the encoder pitch and digital servo drives with high PWM frequencies can reach the performance of linear amplifiers. Future work will focus on a more detailed analysis of linear scales with regard to signal quality, interpolation, sampling frequency and auto calibration as well as on various aspects of CNC controls such as NC cycle time, interpolation frequency and method or setpoint communication strategy.

References:

[1] Brecher, C.; Lindemann, et al.: Analysis of Control and Servo Drive Systems for the Application in Ultra Precision Machining. Proceedings of the euspen 11th International Conference, Como, 2011, ISBN 978-0-9553082-9-1, pp. 303 - 306

[2] Brecher, C.; Lindemann, D.; Wenzel, C.: Influences of Control, Feedback and Servo Drive Systems on Precision Machining. Proceedings of the euspen 12th International Conference, Stockholm, 2012, ISBN 978-0-9566790-0-0, pp. 344 - 347