The New Position Control and Data Acquisition Concept of the Nanometer Comparator

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Abstract. *The Nanometer Comparator, the PTB reference comparator for length graduations, was upgraded with a high precision positioning system using laser interferometric feedback signals acquired with a self-developed phase meter. The position feedback data is transferred by a high speed serial link from the phase meter to an FPGA controller. This upgrade of the Nanometer Comparator led to a 7-fold reduction of the position noise and a 100-fold reduction of the nonlinear motion deviations in the dynamic case.*

Keywords: Optical Interferometry, Position control, FPGA

1. Introduction

The Nanometer Comparator [1] provides traceable measurements of line scales, photomasks, incremental encoders and interferometers in the range up to 540 mm with expanded measurement uncertainties of a few nanometres only. This level of uncertainty can only be reached by operating the optical interferometers, which are well integrated into the mechanical setup, completely in vacuum. In recent years the Nanometer Comparator has been upgraded to provide straightness measurements using a mirror at one sidewall of a Zerodur sample carrier and an additional (y) interferometer system using three measurement beams [2,3]. This heterodyne interferometer system requires six additional input channels to eliminate the perturbation introduced by the use of optical fibers at the interferometer entrance [4]. Therefore, a newly developed phase meter [5] is employed, which also replaced the commercial one currently used for the main measurement (x) axis and the pitch interferometer as well. Consequently, the data acquisition software had to be extended.

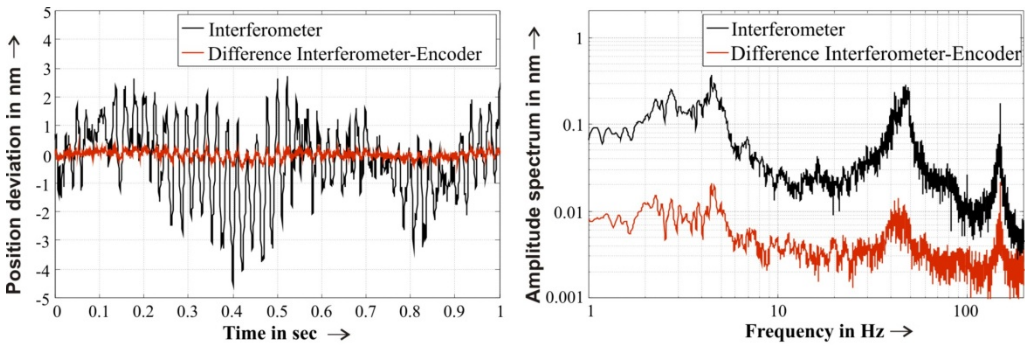

Fig. 1. Left diagram: position noise of the main interferometer (black curve) and differences of the measurement signals of the interferometer and the measurement object (incremental encoder). Right diagram: Related amplitude spectra

In addition, the position noise of the measurement slide disturbs the measurements, which is illustrated in Fig. 1. The black curve in the left diagram shows the position noise of the interferometer and the red one the difference between the interferometer and the measurement object, an incremental encoder in this case. The right diagram contains the related amplitude spectra. They reveal that, although the data acquisition of both displacement sensors has been synchronized by means of a common trigger signal, the position noise appears in reduced form in the position differences and therefore increases the related measurement uncertainty.

The influence will be larger if other sensors, which cannot be synchronized so well to the interferometer, have to be used. A CCD camera, which acquires the image of an optical microscope used in line scale measurements, may serve as an example.

Therefore, in order to reduce the achievable measurement uncertainty, the drive and the related position control system of the Nanometer Comparator needed to be improved.

2. A new position control and data acquisition concept

New drive concept

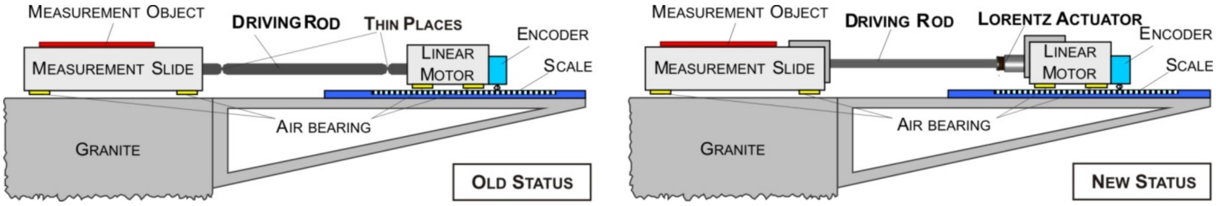

Fig. 2. Mechanical connection of linear drive and measurement slide. Left: Former solution using two thin places. Right: Integration of the Lorentz actuator in the setup. Note: Elements are not to scale.

Fig. 2 shows a schematic of the old and new connection of the linear drive to the measurement slide. The lateral air bearing guides of the motor and the slide have been omitted for the sake of simplicity. In order to minimize the influence of the heat generated by the linear drive on the measurements, the slide and the motor are separated by a carbon fiber driving rod of about 1 m in length. Both use different mechanical guides, which are not perfectly collinear. Therefore, two thin places were used in the former setup to accept the related guiding deviations so that neither the drive nor the slide gets seized in its guide. These thin places, however, reduce the stiffness of the position control loop and do limit the available control loop bandwidth to about 20 Hz. In the new setup, these thin places have been replaced by a Lorentz actuator. The gap between the coil and the magnet can accept the aforementioned guiding deviations. In addition, the Lorentz actuator is used as an additional fast and highly precise fine positioning drive. It uses the vacuum interferometer signals, which exhibit a resolution and nonlinearities of less than 10 pm, as feedback signal and operates at a control rate of 160 kHz. In the former setup, only the incremental encoders of the linear drive with a resolution of 1 nm were used at a control rate of 2.25 kHz.

New control and software concept

The new control concept is illustrated in Fig. 3. The old motion controller (delta tau, PMAC 2 VME) still controls the four coarse positioning drives of the x measurement axis. The Lorentz actuator is controlled by an FPGA board (NI PXI-7854R). It is located together with a second FPGA board (NI PXI-7852R) in a PXI chassis operated by a real-time controller (NI PXIe-8102). The second FPGA board implements the y, yaw, pitch and height control loops. A roll control loop may be added in the future if required. While the y, yaw, and pitch deviations of the measurement slide will also be acquired using interferometers, the height deviations will be sensed by a lateral encoder located at the measurement slide. All these signals are used to control piezoelectric actuators. The height actuators are also used to provide the motion required to focus the optical microscope in the case that line scale measurements are performed. The new phase meter also contains user programmable FPGA units. They are not only used to realize a fast lock-in based phase evaluation algorithm but also implement serial data links that provide position feedback data to the FPGA boards in the PXI chassis. The interferometer data used for the measurements is saved temporally in a ring buffer implemented in onboard memory of the phase meter and transferred over a VME bus to the

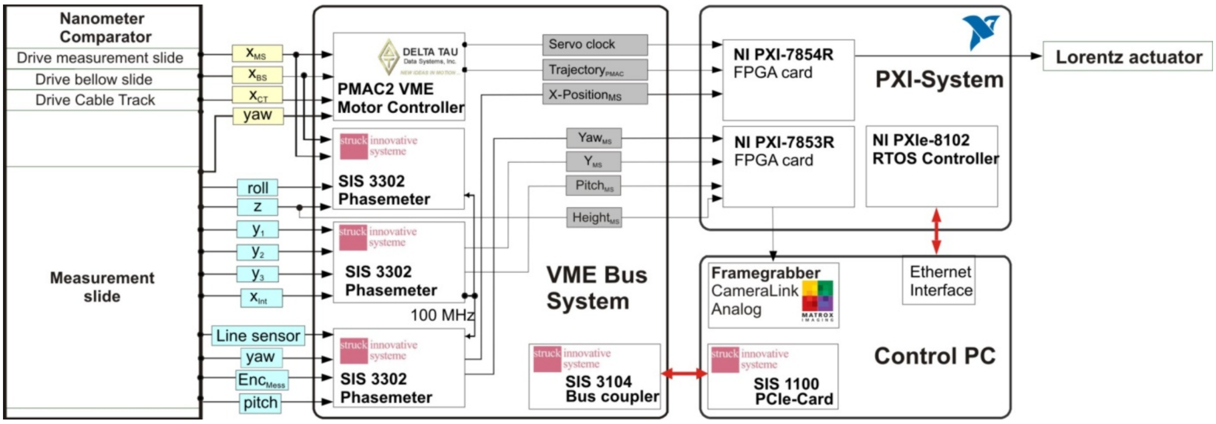

Fig. 3. Principle layout of the new data acquisition and control concept.

control PC and immediately saved to the disc. In this way sample rates of about 50 ksamples / sec can be maintained over hours. In addition, the control PC is used to issue fine motion commands performed with the Lorentz or the piezo actuators, to change the control settings of the FPGA controllers, and to collect and display the monitor data acquired by the FPGA controllers in the PXI system. Furthermore, the PC hosts the image acquisition hardware and acquires the CDD images. Finally, the control PC provides the user interface required to operate and perform measurements with the Nanometer Comparator. Not shown in Fig. 3 is the acquisition of the environmental data, like the sample and air temperature, the humidity or the air pressure, etc. required to evaluate the measurement data [6] which is performed autonomously by other PCs.

The software required to implement this concept consists of four categories. Firstly, the FPGA units on the new phase meter were programmed using VHDL. Secondly, the FPGAs in the PXI chassis and the FPGA controller were programmed in LabView. Thirdly, the image acquisition software and the control program were written in C. Here, LabWindows is used to implement the user interface but the whole program is compiled using Microsoft Visual Studio. Finally, Matlab is employed for an offline data evaluation.

3. Results

Static results

Fig. 4 shows a comparison of the position noise of the measurement slide obtained using the old and the new setup. The spectra shown in the right diagram indicate a significant reduction of the position noise in the frequency range below 50 Hz. In total, the integration of the Lorentz actuator led to a reduction of a factor close to 7.

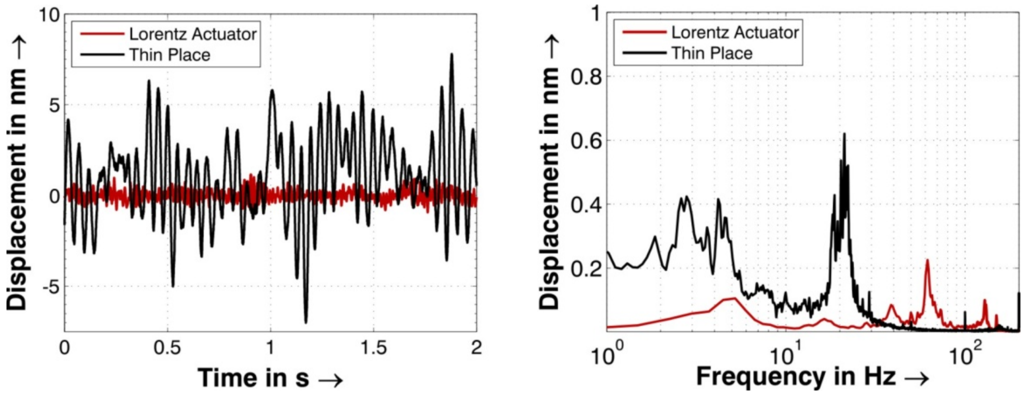

Fig. 4. Left diagram: Position noise of the measurement slide before (black) and after the integration of the Lorentz actuator (red). Right diagram: Amplitude spectra of both signals.

Dynamic results

Because incremental systems are measured dynamically, that is with a measurement speed of about 1 mm/sec, the improvement of the dynamic behaviour due to the use of the Lorentz actuator has been evaluated as well. The figure of merit is here the deviation from a linear motion performed with constant speed. These deviations could be reduced by more than two orders of magnitude, as shown in Fig. 5.

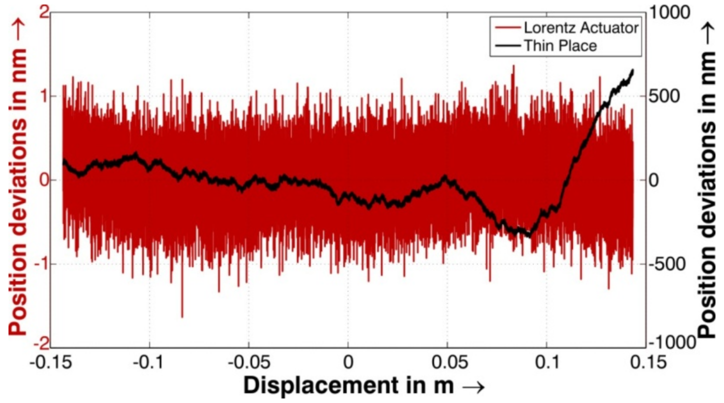

Fig. 5. Nonlinear motion deviations of the measurement slide while moving with constant speed of 1 mm/s before (black) and after the integration of the Lorentz actuator (red).

4. Conclusion

We successfully integrated a fine positioning control system based on a Lorentz actuator in the Nanometer Comparator. It uses vacuum interferometric feedback signals and an FPGA-based controller. It reduced the position noise and nonlinear deviations by a factor of 7 and 100, respectively.

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