Realization of a Large Sample 3D Metrology AFM with Differential Jamin Interferometers

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Abstract

METAS has built a large sample volume AFM with direct 3D traceability which can accommodate objects up to 90 mm x 60 mm x 60 mm. This development is a direct response to an increased interest in traceable nano-dimensional calibrations on technical components which are too large for existing metrology AFMs.

The new AFM design is based on three differential Jamin type interferometers and a commercial 6 axis flexure stage with a range of 800 µm x 800 µm x 200 µm. To follow the topography, the AFM tip is actuated in z-direction with a fast 12 µm piezo stage which is outside the metrology loop. The AFM can operate in static or dynamic mode whereby height and deflection or height, amplitude and phase data are acquired synchronously with the 3D interferometer data by means of a Field Programmable Gate Array (FPGA). Instrument characteristics and first applications are presented.

1 General AFM concept

To accommodate large samples in a metrology AFM a corresponding large reference mirror frame is required. Using Zerodur rods and rings a light weight carrier structure for the three reference mirrors was built which can accommodate samples up to 90 mm x 60 mm x 60 mm (Fig. 1 right). The reference frame with the sample is scanned by a commercial 6 axis stage with a range of 800 µm x 800 µm x 200 µm [1]. The 3 tilting axis are mainly used to improve the quality of the linear scan movements by compensating all angular deviations actively. Autocollimator measurements of the angular deviations were below 4 µrad and mostly linear. The estimated uncertainty contribution of the stage is therefore below 0.6 nm/100 µm scan length at an assumed maximum Abbe offset of 1 mm. Three differential Jamin type interferometers measure the sample position with respect to the AFM tip. The measurement beams fulfil the Abbe condition and the differential measurement shortens the metrology loop considerably. To follow the topography, the AFM tip is actuated with an additional fast 12 µm piezo stage which is placed outside the metrology loop. The cantilever bending is measured using the laser beam deflection method. The AFM can operate in static or dynamic mode whereby height and deflection or height, amplitude and phase data are acquired synchronously. A commercial oscillation controller is used for the amplitude and phase measurements in dynamic mode [2]. The chosen AFM design offers a good sample visibility and an easy sample access. Additionally, a top view zoom video microscope allows to position the tip exactly above the location of interest. Finally, good laboratory conditions, electronics with direct heat evacuation, vibration damping, acoustic isolation and low power dissipation help to reduce noise and drift (Fig. 1 left).

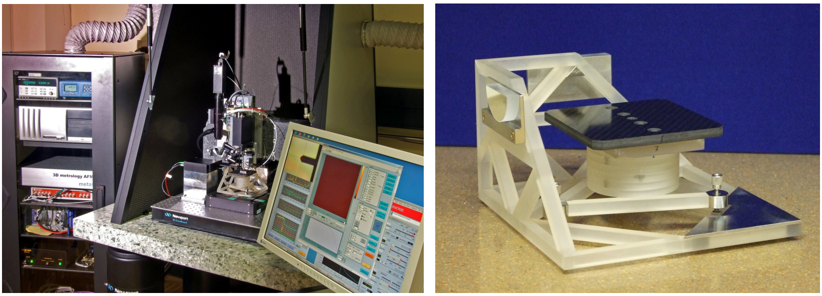

Figure 1: Left: 3D-AFM set-up with electronic rack (left), AFM in the opened acoustic box (centre) and control screen (right). Right: Light weight Zerodur reference mirror system for large samples up to 90 mm x 60 mm x 60 mm.

2 Interferometer design

The chosen interferometers with the incorporated FPGA data acquisition are the most important components needed to fulfil the metrological traceability requirement. The three differential plane mirror interferometers of the Jamin type are based on a previous development at NPL [3]. The METAS built interferometers have additionally optical fibre input for the laser, quartz beam benders at the exit for the special required beam geometry and fast synchronous FPGA data acquisition, correction and output. The measurement of the sample position is made with respect to a reference cube fixed near the tip (Fig. 2).

The interferometer noise depends on the beam path length in air, therefore all beams are guided inside black aluminium tubes to minimise air turbulences. At 40 mm distance the position noise at 10 kHz bandwidth is 0.2 nm p-p. The phase interpolation is improved using an online Heydemann correction [4] resulting in a phase interpolation non-linearity below 0.05 nm. The dead path correction requires an accurate tracking of the refraction index. This is achieved by measuring temperature, humidity, pressure and CO_2 content and using the Edlen formula [5].

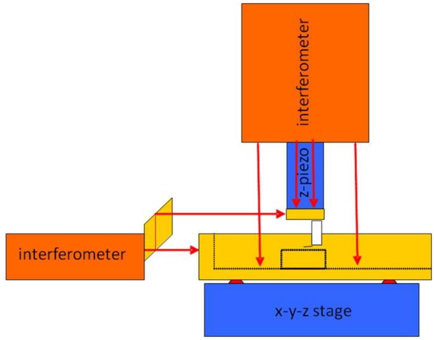

Figure 2: Differential interferometer beam configuration with main beams measuring the sample movement in Abbe and reference beams monitoring the AFM tip position using a small mirror cube fixed to the end of the fast z-stage piezo.

3 Data aquisition

The most crucial data acquisitions with respect to timing and throughput are performed FPGA based. Interferometer fringe counting is possible up to 10 Mhz. The analogue signals are sampled at a rate of 160 kHz fully in parallel on all channels. Sine and cosine signals of the three interferometers are corrected and phase interpolated by a large tangent lookup table. The digital resolution of the FPGA board was set to 20 pm. The interpolated 3D position data as well as the amplitude and the phase signals from the AFM oscillation controller are online averaged to 10 kHz and then directly transferred into the computer by means of Direct Memory Access (DMA). At the same rate the position data is transmitted with a digital parallel port interface to the PI scanning stage controller. This results in an improved stage positioning because the 16 bit capacitive sensors data is replaced by the high resolution interferometer data. The piezo voltage control is finally made through a 20 bit DAC giving a resolution of 0.8 nm/800 µm. The measured 3D point cloud is finally resampled into the usual 2D height matrix which can be evaluated using common image processing software tools.

4 Applications

The new developed instrument will be used to provide various calibration services such as for 1D or 2D grating pitch, step-height, AFM line-width, tip characteriser shape and nanoparticle diameter. Also technical applications such as roughness of microparts, surface texture of precision writing balls, profiler stylus shape deviation and edge radius measurements of cutting tools are planned. Future applications may also require nano-CMM operation modes.

Figure 3 shows a diameter and size distribution calibration of polymer spheres with 200 nm diameter. The acquired raw data images for height, amplitude and phase are of high quality [6].

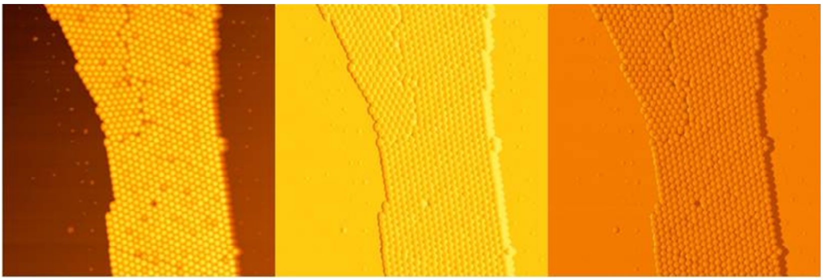

Figure 3: AFM images 8 µm x 8 µm with 1024 x 1024 data points of 200 nm polymer reference particles on mica. Raw data images showing height, amplitude and phase of the AFM tip oscillation (left to right).

References:

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