Calibration of 3D reference standards using metrological large range AFM and calibrated confocal microscopy

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A variety of three-dimensional (3D) microscopes are increasingly used in a number of industrial applications such as roughness measurements and edge contour measurements of diamond cutting tools. Traceability is a fundamental issue to ensure accurate and reliable measurements. Today, the calibration of 3D microscopes requires not only the calibration of the lateral- and height scales, but also the calibration of the flatness error of coordinate planes as well as the shearing of coordinate axes. To satisfy these demands, suitable standards and reference metrology for the accurate calibration of these standards are needed.

The calibration of geometric errors of such microscopes is usually performed by applying a set of height and lateral standards, respectively. However, this sequential method is very time-consuming, as typically a set of several standards has to be measured to complete a calibration. But most importantly, only scale parameters can be calibrated using this method. To overcome this limitation, dedicated 3D calibration reference structures were established, which are suitable not only for the simultaneous determination of the lateral and height scales, but also for the calibration of additional geometric parameters, i.e. all spatial shearing parameters [1]. For automated and statistical over-determined evaluation, the 3D calibration artefacts are equipped with a large number laterally and vertically distributed reference marks (see figure 1). In combination with a dedicated software, these calibration samples are applicable for the 3D calibration of various types of microscopes, i.e. atomic force microscopes (AFM), confocal laser scanning microscopes (CLSM) and 3D-scanning electron microscopes (3D-SEM) and thus enabling comparative or correlative measurements [2].

Prior to its usage, however, the 3D calibration artefact needs to be itself accurately and traceably calibrated. The reference calibration for the 3D calibration structures are performed using the metrological large-range AFM (Met. LR-AFM) of the PTB [3]. This metrology tool is equipped with laser interferometers for measuring the motion along all three axes. The optical frequency of interferometers is calibrated to the frequency standards of the PTB, thus providing measurement results directly traceable to the definition of the “meter”. However, because of the low scanning speed (typically 10 µm/s) of the Met. LR-AFM, a single calibration measurement usually takes up to 3 hours and 1-2 days for the whole calibration procedure. This not only leads to a low measurement throughput, but also to a significant drift during the measurement. Two solutions have been studied to overcome this limitation. The first one is the development of a high-speed Met. LR-AFM which is capable of calibrating the 3D reference standard at a speed over 100 µm/s, which is 10x times faster. The second solution is to apply a calibrated CLSM to calibrate the 3D reference artefact. Each of these two solutions are best suited for specific application needs: the 1st solution for high-end applications where higher calibration accuracy is demanded, while the 2nd solution is for low-end applications with lower calibration costs.

In our work, we will demonstrate the calibration performance of the two solutions mentioned above. Currently, the uncertainty budget determination remains still as a major task in the calibration service. This contribution will address recent research activities towards this target. For instance, in order to estimate the measurement uncertainty, we performed repeated measurements of the 3D calibration artefact, each with different scanning pre-sets, i.e. using different rotations of the sample with respect to the scanning direction. Because of the application of reference marks, transformation of different measurements (which means 3D coordinate triples) is possible, thus allowing to determine the differential parameter variations, i.e. caused by drift effects (figure 2). In addition, we compared our results with computational simulations [4] of the AFM measurements.

Our final goal is to set up an uncertainty budget for 3D calibration standards, thus offering a complete traceable calibration solution for various 3D microscopes applied in industry.

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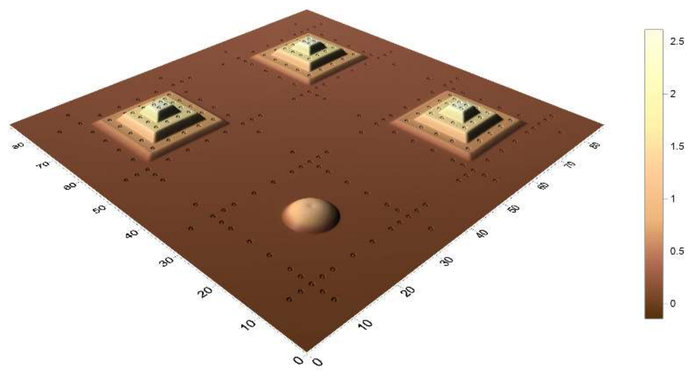

Figure 1: 3D calibration standard, 3D view of AFM measurement data (units in µm)

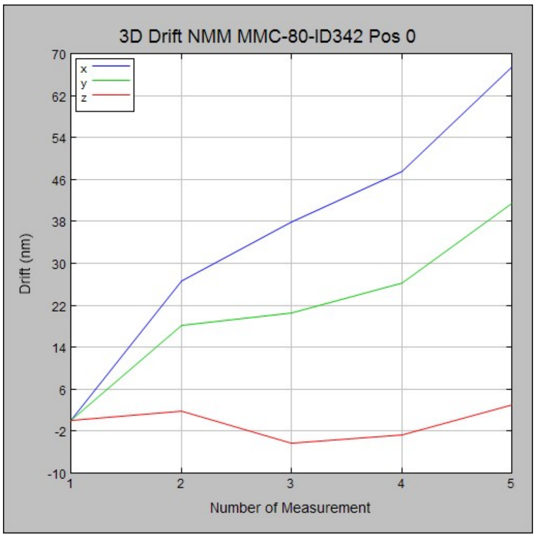

Figure 2: Lateral and vertical drift for repeated measurements by the Met. LR-AFM over 16.8 hours