Fabrication and Validation of a Staircase Artefact for 3D-SEM Calibration

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Abstract

The work deals with the fabrication, calibration and application of two novel artefacts for 3D-SEM calibration. These artefacts are intended for the z-coordinate calibration, which is a crucial issue when performing measurements on 3D reconstructions obtained by employing stereophotogrammetry technique. A five-step artefact with nominal heights ranging from 2 to 50 µm and a three-step one with heights of 2, 5 and 7 µm are described, both encompassing the presence of a common vertical axis. This design allows height measurements at different magnifications and working distances without requiring artefact relocation. The artefacts are suitable for transferring traceability to 3D-SEM techniques at the micrometer scale. The artefact steps were calibrated on a stylus instrument and measured by means of 3D-SEM technique.

1 Introduction

The z-coordinate calibration in 3D-SEM is a crucial issue in connection with establishing measurement traceability. Nevertheless, no suitable reference artefact is available for calibration and performance verification of the so-called 3D-SEM technique, which permits to obtain a 3D reconstruction of an object starting from two SEM images, the stereo-pair, one tilted with respect to the other. Moreover, the possibility to perform the vertical elevation calibration at different magnifications and different working distances is also a desirable prerequisite. This requirement can

be fulfilled, for instance, by means of multiple-step geometries [1]. In this work the fabrication, calibration and application of a novel artefact for 3D-SEM calibration was addressed [2]. The sample is characterized by the presence of a central point, located at the intersection of microscope optical axis (z-axis) and the reference x-y plane (SEM focal plane). A five-step artefact with "staircase" geometry and a three-step one were fabricated, based on the design originally proposed in [1] and calibrated by means of a reference stylus profilometer, to establish measurements traceability. The mean height values for each step were calculated from 3D-SEM measurements and compared to the reference ones. For single-sided steps, a straight line was fitted by the method of least squares to each side of the step transition, and the height was calculated using the software SPIP™ (v 5.1.3, Image Metrology) from the relative position of these two lines extrapolated to the step edge, similarly to what proposed in [3]. An uncertainty evaluation was also performed for both measuring techniques in accordance with the GUM [4].

2 Multi-step artefacts fabrication and calibration

The two multi-step artefacts were fabricated considering the different issues concerning manufacturing, calibration and application as described in [2]. A five-step "staircase" geometry, with heights ranging from 2 to 50 µm, was fabricated by tool grinding, with a stone edge radius of 50 µm, on high speed steel 6 mm diameter bar. A three-step geometry was also fabricated, with heights of 2, 5 and 7 µm, manufactured using Electrical Discharge Machining (EDM) starting from a 3 mm diameter carbide wire. This technology, due to the very small size of the electrode (about 45 µm), guarantees side walls almost vertical, with a curvature radius in the order of 3 to 5 µm. Moreover, very smooth surface finishing is obtainable down to Ra 0.05 µm. Reference measurements, on both the proposed artefacts for 3D-SEM calibration, were carried out using a stylus profilometer, Form Talysurf Series 2 (FTS) from Taylor Hobson, with a tip radius of 2 µm and 1 mm/s tracing speed. Measurements on each artefact were reproduced six times and calibration uncertainties in the range 3 to 10%, for the three-step artefact and 0.3 to about 6% for the five-step one were calculated according to the GUM. A 3D rendering, from stylus profilometer measurements for the two artefacts is shown in Fig.1, where the artefacts geometry, characterized by the presence of a central point, can be seen.

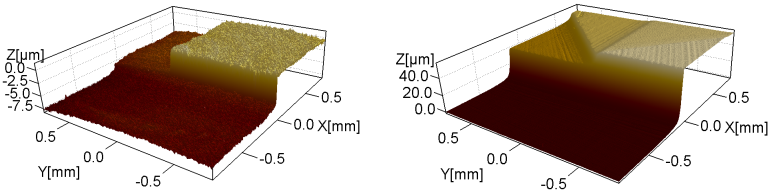

Figure 1. 3D plot from stylus profilometer measurements performed on three-step artefact (left) and on five-step artefact (right).

3 3D-SEM reconstructions and uncertainty evaluation

The applicability of the two artefacts intended for 3D-SEM calibration was verified. 3D-SEM leads to reconstruction, performed in this work using *MeX* by *Alicona Imaging GmbH*, of the artefact geometries, enabling the extraction of multiple profiles from which the height of the steps can be calculated. A number of SEM images of both samples were acquired at magnification 1500x and at the optimum measuring conditions, to be coupled forming the stereo-pairs. An example of SEM image acquired on the five-step artefact and the resulting 3D-SEM reconstruction is shown in Fig.2. The mean heights of the step values, calculated from 3D-SEM reconstructions, were compared to the ones obtained using the reference instrument. An uncertainty evaluation was performed considering the measurements reproducibility, to the workpiece roughness and to the vertical resolution.

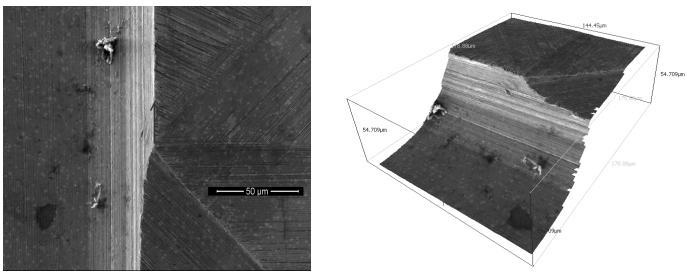

Figure 2. SEM image of the five-step artefact (left) acquired at magnification 1500x, with the centre point positioned in the middle of the field of view. The resulting 3D-SEM reconstruction, for the stereo-pair composed from SEM images acquired ad 0 and 7° tilting is shown on the right.

Considering the three-step artefact, the mean height of the steps, calculated from 3D-SEM reconstructions, showed a systematic underestimation of about 16 %, 4% and

2% for the decreasing nominal values respectively, compared to the reference ones. The expanded uncertainty of the mean step values, calculated for the three steps resulted in a difference ranging from about 500 nm to 300 nm. Considering the five-step artefact an underestimation in the height of the step calculation was again observed, ranging from 2.5% for the highest step to 16% for the smallest step. An expanded uncertainty ranging from a maximum value of 1.9 µm for the highest step, to a minimum of about 0.7 µm for the smallest step was evaluated.

4 Conclusions

A novel artefact for the z-coordinate calibration of 3D-SEM technique is presented in this work. A five-step staircase geometry and a three-step one, both comprising steps converging in a common central point, were fabricated using grinding technology and Electrical Discharge Machining (EDM) process respectively. The artefact steps were calibrated on a stylus instrument according to the GUM and measured on 3D-SEM. Calibration uncertainties in the range 3-10 % for the three-step artefact and 0.3-6.0 % for the five-step one were evaluated. The mean heights of the steps, calculated from 3D-SEM reconstructions, show a systematic underestimation compared to the reference values. The expanded uncertainty of the mean step values for 3D-SEM reconstructions has been also calculated.

References:

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