Practical method for determining the metrological structure resolution of dimensional CT

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Abstract

This work deals with a practical approach for determining the metrological structure resolution in X-ray Computed Tomography (CT) for dimensional measurements. Advantages over other applicable approaches are discussed. The experimental results obtained from the implementation of the method using a micro-CT system are compared with the geometrical unsharpness of CT reconstructions.

1 Introduction

In CT dimensional metrology, the metrological structure resolution describes the size of the smallest structure that can still be measured without exceeding specified error limits [1]. The metrological structure resolution should always be tested and specified in addition to other relevant metrological characteristics, such as length measurement errors and probing errors. It provides additional important information: for example, if smoothing filters are increased, the probing error of form can be improved while at the same time the structure resolution being worsened [2].

Spatial resolution in computed tomography has already been studied thoroughly in literature and several methods for its determination have been published and standardized [2]. However, these methods refer to spatial resolution in the grey-scale voxels (volumetric pixels), which does not take into account the complete measurement chain of CT dimensional measurements, while the metrological structure resolution does so (e.g. it takes into account also threshold determination, surface points extraction and filtering and averaging of surface points). Achieving a good spatial resolution in the grey-scale voxels is necessary but not sufficient for achieving also a good metrological structure resolution.

New practical methods are demanded in industrial CT metrology for fast and reliable determination of metrological structure resolution, encompassing the whole measurement chain [3].

2 Approach for determining the metrological structure resolution

The proposed approach is based on the ‘Hourglass’ reference standard: two calibrated spheres with the same nominal diameter (*D*), enclosed in a carbon fibre tube and physically touching each other as shown in Figure 1-a. The geometry of the sample was chosen as simple as possible, in order to facilitate the evaluation of the structure resolution. Due to the finite structure resolution, the dimensions *d* and *h* of the distorted contact zone in the CT surface reconstruction (see Figure 1-c) increase as the structure resolution increases (see Figure 1-b).

The ‘Hourglass’ standard was preliminary introduced in [2]. A similar concept, using a microtetrahedron sample, was proposed also by Bartscher and Härtig [4] to the ISO TC 213 WG10, but not yet accepted for adoption in the ISO standard on verification of CT measuring systems, which is currently under development.

Using the ‘Hourglass’, the structure resolution is determined by measuring the height *h* on the surface reconstruction. For better accuracy, the value of *h* can be calculated indirectly from the values of the diameters *D* and *d*, since these diameters can be measured with lower relative uncertainty.

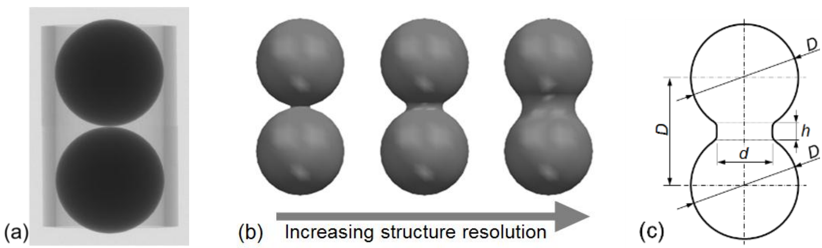

Figure 1: (a) X-ray image of the ‘Hourglass’ standard, with spheres having diameter *D* = 8 mm. (b) Three surface reconstructions obtained from three different CT measurements of the ‘Hourglass’, with increasing structure resolution from left to right. (c) Schematic representation of diameter *d* and height *h* of the contact zone of the surface reconstruction resulting from CT measurement of the ‘Hourglass’.

3 Comparison with geometrical unsharpness

An experimental investigation was conducted using a micro-CT system SkyScan 1172 (SkyScan-Bruker microCT, Kontich, Belgium). The 'Hourglass' standard was measured using the micro-CT system with five different magnifications, obtaining five CT measurements with different voxel sizes: 5.6 µm, 12.5 µm, 22 µm, 27 µm and 50 µm. Each measurement test was repeated three times, for a total of 15 measurement tests performed on the 'Hourglass'.

For each CT measurement test, the surface geometry of the 'Hourglass' was reconstructed and a point cloud was extracted. Each point cloud was analysed using specific elaboration procedures implemented in three-dimensional data modelling and evaluation software (PolyWorks, InnovMetric Software Inc., Canada), determining the actual diameter *d* and height *h* of the contact zone (Figure 1-c).

The values of the height h were compared to the values of the geometrical unsharpness of the respective CT scans. A simplified estimation of the geometrical unsharpness was used [5]:

$$Unsharpness = \sqrt{U_F^2 + U_D^2} \qquad (1)$$

where U_F is the unsharpness caused by the finite focus size (S_F), and U_D is the unsharpness caused by the finite pixel size of the detector (S_D). They were assumed respectively equal to: $U_F = S_F\,(m-1)/m$ and $U_D = 2S_D/m$, where m is the geometrical magnification, defined as the ratio between the source-to-detector distance and the source-to-rotation-centre distance.

For each CT measurement test performed, the ratio between the height *h* measured on the 'Hourglass' and the geometrical unsharpness estimated according to equation (1) was computed. For the 15 measurement tests, the mean value of this ratio was found equal to 1.1, with standard deviation equal to 0.15. The variability of this result was due mainly to the influence of ring artifacts, disturbing the evaluation of the height *h* and the diameter *d* of the contact zone of the surface reconstruction resulting from the CT scan of the 'Hourglass'.

4 Discussion and conclusions

The proposed method using the 'Hourglass' reference standard is definitely more easily applicable than the basic method currently proposed in the guideline VDI/VDE

2617 Part 13 [1], which consists in determining the diameter of the smallest sphere for which the measuring system is able to determine a diameter, with error stated by the CT system manufacturer. The latter method, in fact, may need a large number of calibrated microspheres with different diameters, which definitely are more difficult to be calibrated, handled and CT measured than the two spheres used in the 'Hourglass'.

The experimental investigation carried out in this work demonstrated that the 'Hourglass' approach can be used effectively and efficiently for determining the metrological structure resolution. The investigation showed also that, for the specific conditions used in this work, the ratio between the height h of the contact zone measured on the 'Hourglass' and the estimated geometrical unsharpness of the CT scan is equal to 1.1 on average. Future work should include the following studies: relation to the spatial frequency response of the instrument, investigations using different CT systems and scanning parameters, investigations using samples with different materials and dimensions, and investigations on the influence of different sample orientations and the influence of ring artifacts.

References:

[1] VDI/VDE 2617 - Part 13 (2011). Guideline for the application of DIN EN ISO 10360 for CMMs with CT-sensors. VDI, Duesseldorf.

[2] S. Carmignato, A. Pierobon, P. Rampazzo, M. Parisatto, E. Savio, (2012). CT for industrial metrology - Accuracy and structural resolution of CT dimensional measurements. Proc. of the Conference on Industrial Computed Tomography (ICT); pp. 161–172.

[3] M. Bartscher, H. Bremer, T. Birth, A. Staude, K. Ehrig, (2012). The resolution of dimensional CT - an edge-based analysis. Proc. of the Conference on Industrial Computed Tomography (ICT); pp. 191–200.

[4] M. Bartscher, F. Härtig, (2011). ISO TC 213 WG 10 study on the structural resolution of CT systems for dimensional measurements. ISO TC 213 WG10 meeting; Bejing, September 2011.

[5] P. Müller, J. Hiller, A. Cantatore, M. Bartscher, L. De Chiffre, (2012). Investigation on the influence of image quality in X-ray CT metrology. Proc. of the Conference on Industrial Computed Tomography (ICT); pp. 229–238.