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Influence of the artefact material on the metrological performances of X-ray computed tomography systems

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Abstract
The advantages offered by X-ray computed tomography (XCT), e.g. the capability to inspect and measure complex geometries and non-accessible or internal features in a non-destructive way, are at the basis of its rapid diffusion in the field of manufacturing metrology. However, a large number of influence factors affect the metrological performances of XCT systems. One of the main variables is the material of the inspected object. In this work, the influence of the material of the artefact used for testing the XCT system is addressed. A reference object was developed, consisting on a hole plate which can be made out of different materials and used to evaluate the performances of a metrological XCT system. The position and the diameter of the holes were specifically designed to match with a ball plate that can be used together with the hole plate in a combined way. Experiments were carried out using the objects separately and combined.

X-ray computed tomography, performance verification, material, dimensional metrology

1. Introduction

The capability to inspect and measure complex freeform surfaces and non-accessible or internal features in a non-destructive way, are driving X-ray computed tomography (XCT) towards a rapid diffusion in the field of manufacturing metrology. However, the establishment of the metrological traceability represents still a challenging task as a multitude of factors influence the measurement results. Among those, the material of the object to be inspected is one of the most relevant. Therefore, several materials may lead to artefacts in the reconstructed volume and may require different scanning parameters that can affect the quality of the XCT results. In addition, it is likely in industry to scan multi material components, whose analyses can suffer of other issues, for example in the determination of the surface on the contact zone [1]. The metrological performance verification of industrial CT systems relies on the use of specific reference objects, which can be characterized by different materials and geometries. Since their use can lead to different results, the topic has been one point of discussion for the development of ISO 10360-11 [2,3]. It is therefore important to study the effects that may characterize the scan of different materials, including the impact on the process of metrological performance verification and acceptance testing of XCT systems. In order to investigate the impact of the material on the results of the performance verification of XCT systems, an experimental study was designed and a dedicated reference object was developed.

2. Experimental set-up

An experimental study was developed in order to evaluate the impact of the artefact material in the results of performance verification of XCT systems, following the procedures proposed in the current draft of ISO 10360-11. A hole plate was designed for the study (see Figure 1a). 56 cylindrical features of 2.0 mm diameter are positioned in a way to match with the position of the spheres of the ball plate presented in [4], which was used in this study as well. A first version of the hole plate was manufactured out of aluminium 1050 and calibrated by tactile coordinate measuring machine (CMM) measurements. Three repeated XCT scans of the two objects (hole and ball plate) were performed individually and in a combined configuration at a fixed geometrical magnification, with a voxel size of 20 µm. The three different configurations (hole plate, ball plate and combined object) were scanned in two orientations (see Figure 1 b and c), observing the volumetric length measurement error (E_{vol}) and, when the ball plate was scanned, the probing error of size (P_S) and form (P_F). In the following, we will refer to the ball plate and to the hole plate as to CTBP and HPAl respectively.

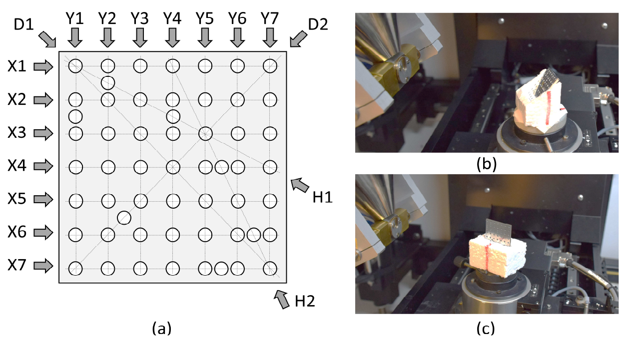

Figure 1. Hole plate used for in this work. The lines considered in the study are indicated in figure (a). Hole plate inclined at 45° (b) and in the vertical orientation at 90° (c).

The experiments were performed by mean of a metrological CT system (Nikon Metrology MCT225), using a single set of scanning parameters for all the object configurations, as stated in Table 1. The 3D reconstruction was performed via the filtered backprojection algorithm implemented in the software CTPro 3D (Nikon Metrology, UK). The surface determination and the dimensional measurements (i.e. cylinder and sphere center-to-center distances and spheres form errors) were conducted using the analysis and visualization software VGStudio MAX 3.2.3 (Volume Graphics GmbH, Germany).

Table 1. XCT scanning parameters adopted in the experimental study

Voltage / kV	110
Current / µA	150
Exposure time / s	1
Frame averaging	1
Voxel size / µm	20
Nr. projections	1000

3. Results

Analysing the length measurement errors obtained using the CTBP and the HPAl singularly, clearly showed differences. Figure 2 shows the values obtained with the objects in the vertical (90°) and inclined (45°) orientations; in particular the errors increase with the objects oriented at 45°, more critically considering the HPAl than the CTBP.

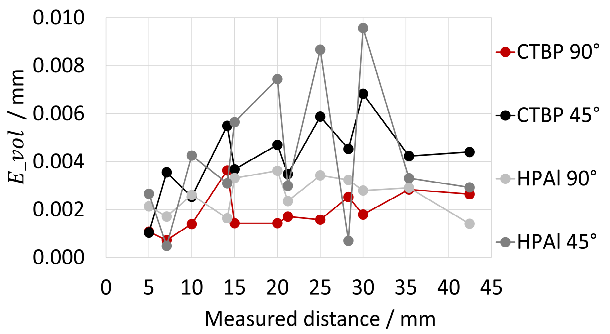

Figure 2. Volumetric length measurement errors calculated on the CTBP and the HPAl scanned singularly in both the orientations (45° and 90°).

Figure 3 reports the errors found in the measurements of the distances between the CTBP sphere centres and between the HPAl cylinders, scanned singularly and in combination, in the vertical orientation. The results show that the presence of the additional material leads to significant effects. In particular, a relevant increase can be observed in E_{vol} when determined on the hole plate assembled with the ball plate.

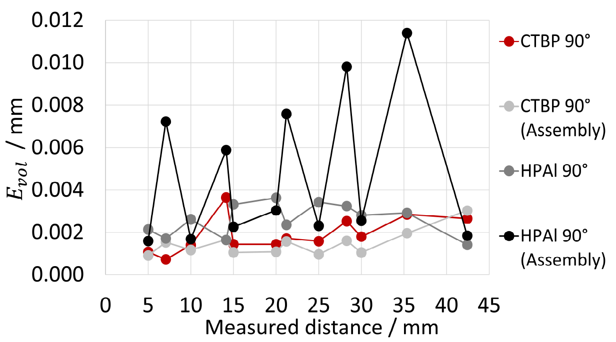

Figure 3. Length measurement errors calculated on the CTBP and the HPAl scanned singularly and assembled (Assembly) oriented at 90°

With the object at 45°, the effect of the presence of the hole plate on the errors calculated using the ball plate is more critical, as indicated in Figure 4.

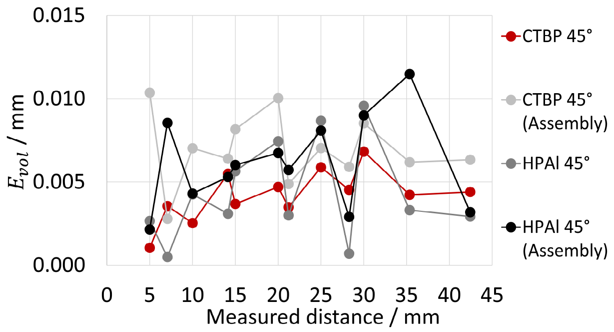

Figure 4. Length measurement errors calculated on the CTBP and the HPAl scanned singularly and assembled (Assembly) oriented at 45°

The presence of the hole plate has a significant impact on P_F, which increases from 14.1 µm and 13.8 µm, when scanned singularly, to 36.8 µm and 22.6 µm in the combined configuration, respectively with the object inclined at 45° and 90° (see Figure 5). Moreover, while testing the CTBP singularly led to similar results at 45° and 90°, the results obtained with the combined object showed significant differences depending on the object orientation.

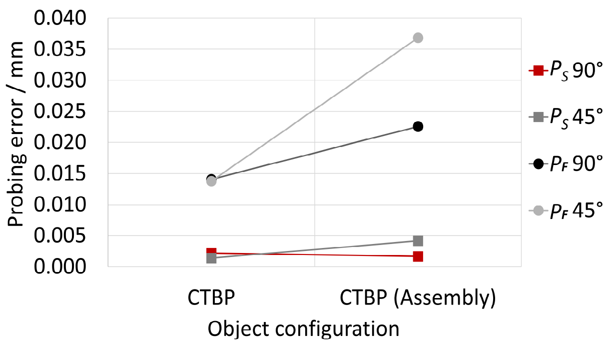

Figure 5. Probing error of size and form measured considering all the spheres of the CTBP scanned singularly and in combination with the HPAl for both the object orientations (45° and 90°).

4. Conclusions

This work is a part of a wider study that aims at evaluating the impact of different materials in the metrological performance verification of XCT systems, following the procedures currently being considered in the ISO 10360-11 draft standard. In this work, the objects design was presented and a preliminary experimental investigation was conducted using a ball plate and an aluminium hole plate.

The results obtained allow to plan future experiments to study the influence of the artefact material on CT dimensional measurements, investigating different materials, varying the scanning parameters and testing different orientations.

References

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