Creating a Multi-Material Length Measurement Error Test for the Acceptance Testing of Dimensional Computed Tomography Systems

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Abstract

Non-destructive testing (defects detection, material characterization), reverse engineering, fibre orientation, and more recent coordinate metrology represent the broad range of applications of X-ray computed tomography (CT) [1]. Dimensional inspections of multi-material assemblies are characterized as a promising application for CT today and in future. However, the use of CT as a coordinate measurement system opens up new challenges to the technology. Reliability of multi-material CT measurements is still open issue due to the complexity of multi-material measurements and due to the fact that it is not covered in the current guidelines and standard drafts [2]. Thus, this paper presents – as part of a multi-material acceptance test and to create trust in multi-material CT measurement – a new design and concept for multi-material length measurement error testing and discusses the test design based on the first experimental results. The paper attempts to perform a critical analysis of the new design – a multi-material hole cube – and tries to perform several verification steps of the concept.

Keywords: Acceptance testing, Multi-material measurements, Dimensional computed tomography (CT), Standardization, Length measurement error (E-test)

1 Length measurement error acceptance testing

While the tactile coordinate measurement systems (CMS) technologies have reached a satisfying level of reliability, a lot of effort has been devoted to bring CT to the same level of trust. Indeed, acceptance testing creates trust in the CMS by helping to reach traceability to the SI-unit (metre) for the measurands under study, and by creating specification definitions, enabling decision for both CMS users and manufacturers. Thus, CT users and manufactures share a growing interest in standardization. In 2010, the ISO Technical Committee 213 Working Group 10 started to develop an ISO 10360 standard focused on acceptance testing for CT [2]. Acceptance testing is the main topic of the well-established international ISO 10360 series of standards. The ISO 10360 concept requests to perform an overall test of the entire performance of a CMS, assumed as an integrated system. Thus, the test shall cover the dominant error behaviour of the CMS under study. Another important concept of acceptance testing is to assess local and global performance of the error characteristic of a CMS. Local performance is assessed as probing error test (P-test) by means of measuring size and form of a (small) test sphere. Global performance is assessed as length measurement error test (E-test) by means of measuring (long) length reference standards (e.g. hole plate, step gauges, etc.). Length measurements can be evaluated as uni- and bi-directional measurements, see Figure 1. Discussions in ISO stated that bidirectional probing shall be mandatory while unidirectional probing stays optional when performing E-test [2]. Unidirectional lengths can be evaluated using multi-point measurements (centre-to-centre distances based on a fit), point-to-point and patch-based measurements, while bidirectional lengths can be evaluated as point-to-point and patch-based measurements. The use of patches has been introduced in the scope of acceptance testing in ISO 10360-8 for optical sensors due to the fact that it enables more stable results by reducing the influence of the sensor noise. Common to the current guidelines and draft standards for CT is that they consider only the mono-material case. I.e. the tests are not designed to make statements about the performance of the multi-material CT measurements. A further observation is that some of the proposed tests have partially multi-material effect included, e.g. [3].

2 Multi-material length measurement error reference standard

This paper addresses the challenge of creating a multi-material acceptance test for dimensional CT – specifically the multi-material length measurement error test (E-test). The multi-material probing error test (P-test) is addressed in a further
contribution to iICT2017. An important remark is that the whole multi-material test is designed to complement the mono-material test. Thus, this contribution presents a new multi-material reference standard design for the E-test and discusses first results based on experimental CT data. The new reference standard, multi-material hole cube (HC), is presented in Figure 2. It has size of 30 mm × 30 mm × 30 mm featuring 17 holes inside and 12 “V”-shaped grooves outside. The design consists of two symmetric parts made of different materials, it also features a step-like “cut” shape enabling different multi-material ratios along the standards’ height, see Figure 3. The HC design also allows in- and inter-material measurands in a multi-material scenario as well as measurands in mono-material scenario (depending on the orientation in the CT, mono-material measurements can be performed e.g. in G1 and G12, see Figure 3). Besides this, the positions of the holes are designed to have at least 3 independent lengths in 7 main directions, featuring lengths from 2 mm to 29 mm. The grooves are used to indicate different heights and thus different material ratios.

In total 6 HC standards are created, 3 mono- and 3 multi-material. Reference measurements of the HC are performed using a tactile CMS. All 17 holes are measured in 7 heights (height indicated by the groove position). For each groove, 7 circumferential lines in different heights (circumferential lines distance 25 µm) are measured, see Figure 3. In total 0.5 Mio points are obtained from the tactile scanning measurements.

The same measurement strategy is applied to the CT data. This measurement approach allows flexibility of the measurands, i.e. it enables the use of single-point, multi-point and patch measurements, improving comparability between the CMSs. Distances using different measurands (e.g. centre-to-centre, patch-based measurements) are calculated using scripting-based analyses.

Due to its design, the HC enables investigation of potential multi-material effects on the length measurements. 272 mono-material lengths in a multi-material scenario; 274 in- and 238 inter-material measurements in a multi-material scenario are possible. Additionally, 160 lengths using the unusual measurands where a single primitive (e.g. cylinder, circle) is created by two materials, see e.g. H9 at height of G4 in Figure 4.

<table>
<thead>
<tr>
<th>Material ((d_2/d_1))</th>
<th>Multi-material</th>
<th>Mono-material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absorption coeff. ratio ((\mu_2/\mu_1)) @200 kV, 1 mm Cu</td>
<td>Al/Cesic</td>
<td>Al/Ti</td>
</tr>
<tr>
<td></td>
<td>0.9</td>
<td>0.4</td>
</tr>
</tbody>
</table>

Table 1: Materials for the multi- and mono-material E-test and their absorption coefficient ratios.

3 Outlook

This work presents the new multi-material hole cube reference standard for multi-material length measurement error testing. Based on first results of the HC an investigation of the multi-material effects on the length measurements is carried out. The study tries to answer the question if a CT is able to measure precisely short and long length in a multi-material scenario as well as how much the measurement is influenced by a potential multi-material effect. Different mono- and multi-material HCs using 3 different materials have been manufactured and real CT scans are performed. CT results are compared with tactile reference data. Additionally relative analyses are performed by comparison between multi- and mono-material CT results. The paper tries to create input for standardization of dimensional CT and ends with a first evaluation of the multi-material reference standard concept.

Acknowledgements

This work is funded by the EU Marie Curie Initial Training Networks (ITN) – INTERAQCT, Grant agreement no.: 607817, beneficiary no.: 7, more information can be seen on http://www.interaqct.eu.

References


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