Creating a Multi-material Probing Error Test for the Acceptance Testing of Dimensional Computed Tomography Systems

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Abstract

The new requirements of quality assurance of inner and outer structures in complex multi-material assemblies encouraged the use of industrial X-ray computed tomography (CT) in coordinate metrology [1]. The use of CT as a coordinate measurement system (CMS) opens up new challenges, typically associated with the performance verification, specification definition and thus standardization. When performing multi-material measurements, further and new challenging effects are included in the measurement, e.g. the proper selection of scanning parameters in multi-material scenario and the appropriate choice of parameters for surface determination in a multi-surface setting [2]. Thus, this paper presents – as part of a multi-material acceptance test and to create trust in multi-material CT measurement – a new concept for multi-material probing error testing and discusses the test design and the first experimental results. The paper attempts to perform a critical analysis of this new concept–featuring a compound sphere made of two half spheres of different materials – and tries to perform certain verification steps including the analyses of geometrical features of the new standard.

Keywords: Acceptance testing, Multi-material measurements, Computed tomography (CT), Standardization, Probing error test (P-test)

1 Acceptance testing of dimensional CT

In 2011, the German engineers association (VDI/VDE) issued the first guideline for acceptance testing and performance specification of dimensional CT (VDI/VDE 2630-1.3). Acceptance testing is also the main topic of the well-established international ISO 10360 series of standards, currently focused on tactile and optical CMSs. In 2010, the ISO Technical Committee 213 Working Group 10 (ISO TC 213 WG 10) started a similar development of an ISO 10360 standard focused on acceptance testing for CT as a CMS [3]. According to ISO 10360 principles, the main objective of acceptance testing is to perform an overall test of the entire performance of the CMS, assumed as an integrated system (i.e. black-box-like system).

Basically, the test creates trust upon the CMS, thereby helping to achieve traceability to the SI-unit (metre) for the measurands under test and creating comparability with CMSs adopting different sensor technologies. Another important principle of acceptance testing is to assess global and local performance of the error characteristic of a CMS. Global performance is assessed as length measurement error test (E-test) by means of measuring (long) length reference standards (e.g. hole plates, step gauges, ball plates, etc). Local performance is assessed as probing error test (P-test) by means of measuring size and form of a (small) test sphere, see Figure 1. According to recent discussion in ISO, P-test for form might be evaluated as probing dispersion value ($P_{\text{Form.Sph.D95\%::CT}}$) and probing form error ($P_{\text{Form.Sph.1x25::CT}}$); and P-test for size might be evaluated as probing error “all” ($P_{\text{Size.Sph.All::CT}}$) and probing size error ($P_{\text{Size.Sph.1x25::CT}}$) (see [3] for notation). $P_{\text{Form.Sph.1x25::CT}}$ and $P_{\text{Size.Sph.1x25::CT}}$ may be determined by a least-square fit of 25 representative points on a test sphere (patch-based analyses). Common to all guidelines and draft standards is that they deal with the mono-material case. I.e. the tests are not dedicated to make statements about the performance of that CT in use as CMS when measuring multi-material objects. A further problem is that some of the proposed tests have a certain percentage of multi-material effect included. Examples are mono-material reference standards which are mounted on a different material, while during test both materials are penetrated by X-rays and create effects in the test.

2 Creating a multi-material probing test

This paper addresses the challenge of creating a multi-material acceptance test for dimensional CT – specifically the multi-material probing error test. The multi-material length measurement error test is addressed in a further contribution to iCT2017. An important remark is that the whole multi-material test is designed to complement the mono-material test. This contribution
presents a new concept for multi-material probing error testing and discusses the test design itself and the experimental data when performing first tests.

The multi-material probing error test uses the accepted approach of the mono-material test performed with a “test sphere”. In contrast to the mono-material case, the multi-material scenario comprises a compound test sphere consisting of two half spheres made of different materials. The two half spheres have (nominally) the same size and geometry. For the present experimental study, mono- and multi-material spheres of size 9/16 inches (about 14.3 mm in diameter) consisting of half spheres made of 3 different materials are used. Materials: silicon nitride (Si$_3$N$_4$), aluminium oxide (Al$_2$O$_3$) and lead-free glass N-SF6 were selected due to their good mechanical proprieties and dimensional stability as well as appropriate X-ray attenuation coefficient, see Table 1. In order to obtain a multi-material sphere, the half spheres are mounted and glued together using epoxy resin-based glue, see e.g. Figure 2. The multi-material spheres are calibrated using a tactile CMS. Thus, the investigation presented in this paper consists of mono- and multi-material scenarios performing in-material and inter-material measurements, i.e. measurands comprised by one material only and measurands comprising by two materials, respectively.

Although the half spheres’ nominal diameters are identical, due to technological limitations the half spheres are actually different, featuring different diameters and different cut positions (both in the µm range). Besides this, several mechanical misalignments are potentially present in such sphere assembly, e.g. centre position shift of the half spheres and a gap caused by the glue. Thus, the overall sphere size and form might be severely impaired by the mounting-related misalignments. Therefore, the evaluations are performed in the two half spheres separately. Although, this new approach differs from the standard mono-material P-test, the proposed multi-material test is an addition to the standard test and it should be as efficient as possible avoiding redundant information. The information obtained by the separate half spheres has shown to be more sufficient for the analyses.

### 3 Outlook

This work discusses a new multi-material probing error test (P-test) scenario based on a compound sphere consisting of two half spheres made of different materials. The test tries to answer the question if a CT CMS is able to measure size (i.e. diameter) and form of the multi-material sphere (i.e. half spheres in the presence of different materials). A set of multi-material compound spheres featuring 3 different materials have been created and tested. Real CT scans in mono- and multi-material scenarios comprising in- and inter-material measurements are considered. The paper tries to create input for standardization of dimensional CT and ends with a first evaluation of the proposed test scenario.

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## References


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