Precision Engineering xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Precision Engineering

journal homepage: www.elsevier.com/locate/precision

Interlaboratory comparison of a physical and a virtual assembly measured by CT

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ARTICLE INFO

Keywords:
Computed tomography (CT)
Measurement uncertainty
Assemblies

ABSTRACT

In a comparison including 20 laboratories, a physical as well as a virtual assembly provided as two data sets were used to investigate measuring and post-processing approaches in computed tomography, CT. Different procedures were used in the comparison including one simulating in-line measurement. The comparison demonstrated that: (i) a tangible improvement in the use of CT compared to previous comparisons; (ii) most of the participants were able to reduce their scanning time by more than 70% without increasing the length measurement errors; and (iii) most of the participants can further reduce their uncertainties, thereby reducing the tolerance size that can be inspected using CT in industry.

1. Introduction

X-ray computed tomography, CT, is recognised as a game-changing technology in the field of quality control of assemblies [1,2]. It is known that dimensions may differ between non-assembled and assembled components, explaining why assemblies may fail, even if all non-assembled components are within specifications. Assembly inspection based on CT measurements ensures more reliable information than any destructive testing method, which irremediably deforms the assembly. Despite the growing interest in the use of CT for assembly inspection in industry, only a small body of literature is available on this matter. This paper reports on the results of the InteraqCT comparison representing the first comparison focused on CT inspection of assemblies. Two assemblies reflecting parts commonly inspected in industry in terms of materials and measurands were selected for the comparison. In contrast to previous comparisons that only focused on physical items [3,4], the present comparison has introduced a virtual item as a scan produced and reconstructed by the coordinator, and then distributed electronically to all participants. The virtual item represents an evolution of the concept of softgauge used in the measurement of surface texture [5].

2. InteraqCT comparison: items and measurands

The InteraqCT interlaboratory comparison on CT of assemblies was organised by the Department of Mechanical Engineering, Technical University of Denmark (DTU) and carried out as an activity within the Marie Curie ESR Project INTERAQCT. The comparison was carried out with a parallel circulation in the period from June 2015 to September 2016, involving 20 laboratories from 7 countries: Austria, Belgium, Denmark, Germany, Italy, Singapore, and the UK. National metrology institutes, equipment manufacturers, universities, research centres, and industrial companies were all represented in the comparison. All the end-user participants have a keen interest in using CT for quality control of assemblies. The assemblies used in the comparison are shown in Fig. 1. The physical assembly is a two-component item comprising a 56-mm miniature cylindrical step gauge, machined from an aluminium rod, and a tube made of borosilicate glass. The tube presents an inner diameter of 17.5 mm and an outer diameter of 19.4 mm. The physical assembly is designed to avoid the contact between the step gauge and the glass in the areas used for defining the measurands, ensuring that any post-assembly deformation is minimised. The physical assembly comprises two kinds of measurands: the gauge measurands and a gauge-tube measurand, making it the first of its kind. The gauge measurands are the lengths defined as the distances between two flanks of the step gauge. The gauge-tube measurand is the length defined as the gap distance between the top of the first tooth of the gauge and the inner diameter of the tube. The measurands selected on the physical assembly are shown in Fig. 2. $L1$ and $L4$ are two unidirectional lengths [6] with nominal sizes of 3.5 and 14 mm, respectively. $L2$ and $L3$ are two bidirectional lengths [6] with nominal sizes of 3.5 mm and 10.5 mm, respectively. T is a gauge-tube measurand with a size of 3.5 mm. The measurands were selected to compare the measurement error and measurement uncertainty estimation between gauge and

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http://dx.doi.org/10.1016/j.precisioneng.2017.08.018
Received 31 May 2017; Received in revised form 11 August 2017; Accepted 18 August 2017
0141-6359/

Fig. 1. (Top) The physical assembly and (bottom) the industrial assembly used to produce the virtual assembly.

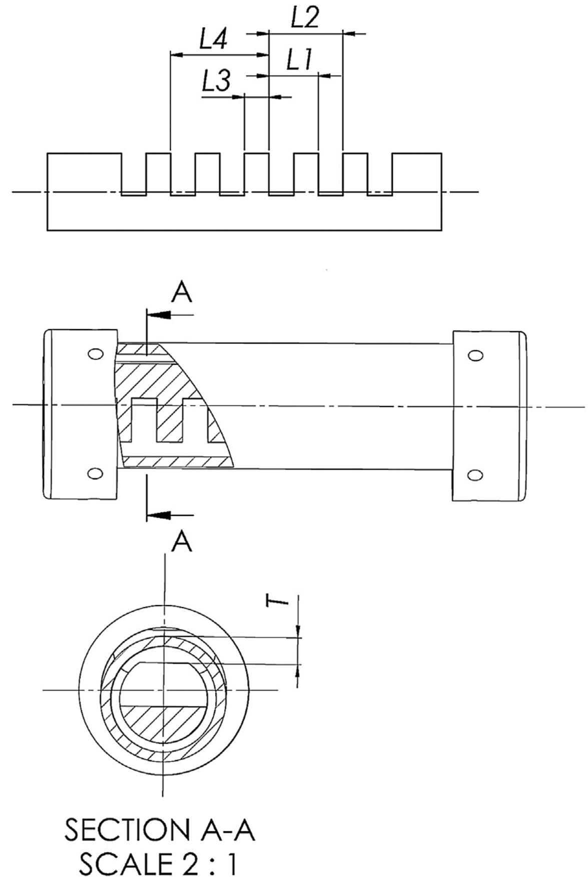

Fig. 2. The overview of measurands of the physical assembly: *L*1, *L*2, *L*3, *L*4, and *T*.

gauge-tube measurands as well as between unidirectional and bidirectional measurands. It is known that a unidirectional measurand is very robust against any potential local error of CT, e.g. surface determination, beam hardening, noise, etc., whereas a bidirectional measurand is not [1,2,6]. 20 samples were manufactured, imaged and their absorption coefficient values were compared using the Beer–Lambert law [1]. The maximum variation in the absorption coefficient value among the samples was quantified to be less than 15%, leading to the conclusion that the samples were adequately homogeneous for use in this comparison. The imaging of the samples was conducted on a Nikon XT H 225 ST CT (Voltage = 150 kV, Current = 175 µA, voxel size = 40 µm, and exposure time = 1 s).

Virtual assembly is based on imaging of a subassembly of an insulin injection device. The industrial item includes an inner component, made of polyoxymethylene, and an outer component, made of ABS-polycarbonate. The generation of the virtual assembly was carried out using two set of scanning parameters in order to obtain data sets with two different image quality levels. The measurands selected on the virtual assembly are shown in Fig. 3. The measurands were all selected on the outer component. *D*1 and *D*2 are two Gaussian diameters with nominal sizes of 3.3 mm and 5.5 mm, respectively. *D*1 is an inner diameter, while *D*2 is an outer diameter. *R*1 is unfiltered roundness of *D*1. *C*1 is coaxiality of *D*2. The measurands were chosen to provide an increasing level of difficulty for the participants. The use of a virtual item yields the following advantages over a physical one: (i) it enables determination of whether CT post-processing has an effect on the accuracy of CT measurements by uncoupling scanning and post-processing; (ii) it allows a parallel circulation based on a same item, thereby avoiding problems associated with the sample homogeneity; (iii) it gives significant cost savings associated with manufacturing, calibration, and shipping; (iv) it reduces the workload of participants as no scan is required for this item.

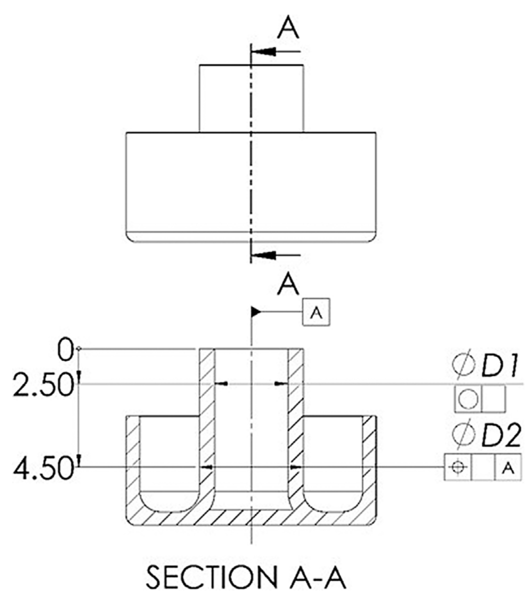

Fig. 3. The overview of measurands of the virtual assembly: *D*1, *D*2, *R*1, and *C*1. The measurands were all selected on the outer component.

3. Measurement procedures

Two scanning procedures were defined for the physical assembly. The first approach, coded as “Own Choice”, does not apply any scanning restrictions on any of the scanning parameters. The second one, coded as “Fast Scan”, introduced a series of limitations such as scanning time less than 1 h, including preliminary corrections, no image