Dimensional X-ray Computed Tomography and its Evaluation Method of Measurement Capability

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Abstract

An X-ray computed tomography (CT) system that is capable of dimensional measurements is incleasingly propergating in our life because the realization of simultaneous nondestructive dimensional measurements for outward forms and inward forms on dense spatial points in short time duration remarkably facilitates production loop. However, the X-ray CT is still not applicable to all of industrial object to date. National metrology institute of Japan have been continued performance evaluation of X-ray CT to understand the dimensional metrology by X-ray CT[1]. Examples of test procedure using simple shaped objects and trial measurements on realistic objects are presented.

Keywords: Radiographic Testing (RT), X-ray CT, dimensional measurement, standardisation, coordinate measuring machine

1 Introduction

In recent years, dimension measurement using DXCT (Dimensional X-ray Computed Tomography) has been rapidly penetrating into industry as it enables non-destructive inspection in industrial products in a short period of time. In addition to being able to see the invisible position and the interior of the product by the nondestructive inspection capability, we can not overlook the measurement capability that makes it extremely easy to measure the outline of the product. The ability to make measurement on high density positions at once has strong affinity with digital engineering. Such measurements have been carried out for a long time by tactile and optical coordinate measuring machines. On the other hand, since DXCT is a relatively new device, researches on methods to realize highly accurate dimensional measurement methods for variety of objects are still being conducted. The measurement principle of X-ray CT is completely different from conventional coordinate measuring machine (CMM). Whereas the conventional CMM directly detects the position of the surface, in the X-ray CT, the transmitted image captured from many directions over 360 degrees is synthesized and reconstructed, and the spatial distribution of attenuation coefficients on the trajectory through which X rays pass through. Therefore, in order to measure the dimension of the product by X-ray CT, it is necessary to know the precise position of the interface or surface of the product from the three-dimensional volume data, which is the spatial distribution of attenuation coefficients obtained by X-ray CT. From the model thus formed, measurements of dimensions and shape are performed. In X-ray CT, since the model is obtained from the transmission image, the whole physical interaction during transmission affects the determination of the surface. The dimension measuring device uses a gauge consisting of a combination of simple shapes to inspect the measuring capability and calibrate the device parameters. In order to evaluate the overall measurement capability by DXCT, it is considered to use a combination of a gauge that is not easily influenced by physical interaction and a gauge greatly affected. In this report, research on methods to evaluate measurement performance is reviewed and some application is presented.

2 Evaluation Method

2.1 Specifications of the DXCTS used in this work

An investigative DXCT system used in this work is SMX-225CTS constructed by Shimadzu Corporation (Fig. 1). The specifications are as follows. It is equipped with a microfocus X-ray source with maximum tube voltage of 225 kV and maximum input power of 135 W. Image detector is a flat panel detector (FPD) of size 200 mm by 200 mm. This system has stages with freedoms of motion, magnification axis, sample rotation and elevation. Rotational error is less than 1μm. Inside of the measurement room is temperature controlled with a climatization system. The system has maximum transmission power to observe about 100 mm for aluminum.

Fig. 1 Outside view of SMX-225CTS system.

2.2 Evaluation

The performance of the DXCT system has been tested with several ways. The key evaluation items of the DXCT are the spatial resolution, the sensing error in the micro region and measurement volume deformation in global area.

One of the spatial resolution evaluation method is to viewing the resolution chart with the radiographic image. Figure 2 shows the overview of a resolution chart and its radio graphic image captured with the DXCT under test. The length of the smallest pitch which is distinguished as completely separated elements in the image is evaluated as the spatial resolution of the system.

The sensing error in the micro region is evaluated through the measurement of small sphere with high magnification. The detected diameter of the sphere using the DXCT is compared against its calibrated diameter. Simultaneously, the sphericity of the observed sphere is evaluated (Fig. 3). The estimated diameter measurement error and the sphericity shows the sensing bias of the anisotropic characteristics of the system.

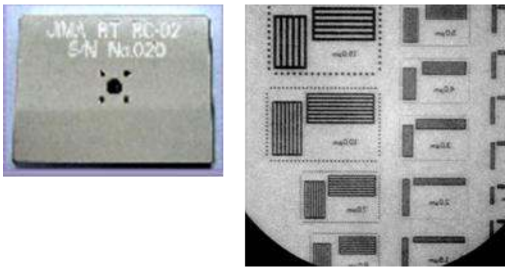


Fig. 2 Resolution test with JIMA chart RC-02.

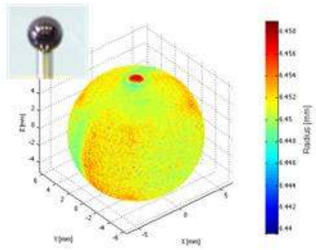
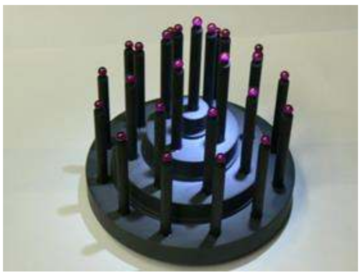
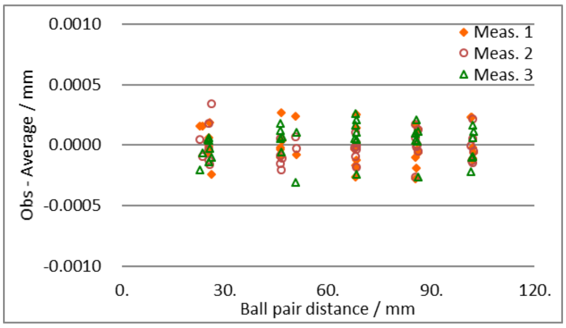


Fig. 3 Sensing error evaluation using a sphere.

Tests with a stylus forest shows us the deformation of the measurement volume. Figure 3 shows a stylus forest and the length measurement stability in short term. Figure 4 illustrates the values of the length measurement error in directions. The difference of the length measurement errors in directions shows the deformation of the measurement volume of the system.



a) Photograph of the forest



b) Short term repetitive measurement of ball pairs

Fig. 3 Stylus forest and length measurement stability of the DXCT in short term.

Figure 5 a) shows a schematic drawing of the kinematic model of a cone-beam X-ray CT system. The system includes several number of kinematic parameters shown in Fig. 5 a). When evaluating the dimensional measurement performance of a coordinate measuring system like a CMM, the total deformation of the measurement volume of the system is verified rather than the individual kinematic parameters errors. In the case of a CMM, the deformation of the cubic-measurement-volume to the parallel-piped-one is evaluated and parameterized as scale errors and angle errors. Those errors are estimated with the length measurement errors in representative directions in the measurement volume of the CMM. As well as CMMs, the deformation of the measurement volume of dimensional X-ray CTs are evaluated with the similar manner (Fig. 5 b)).

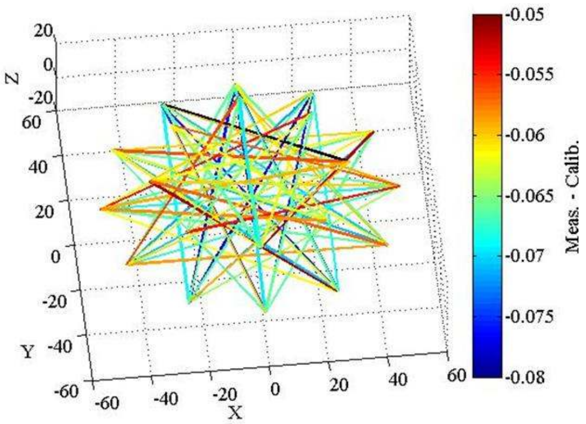
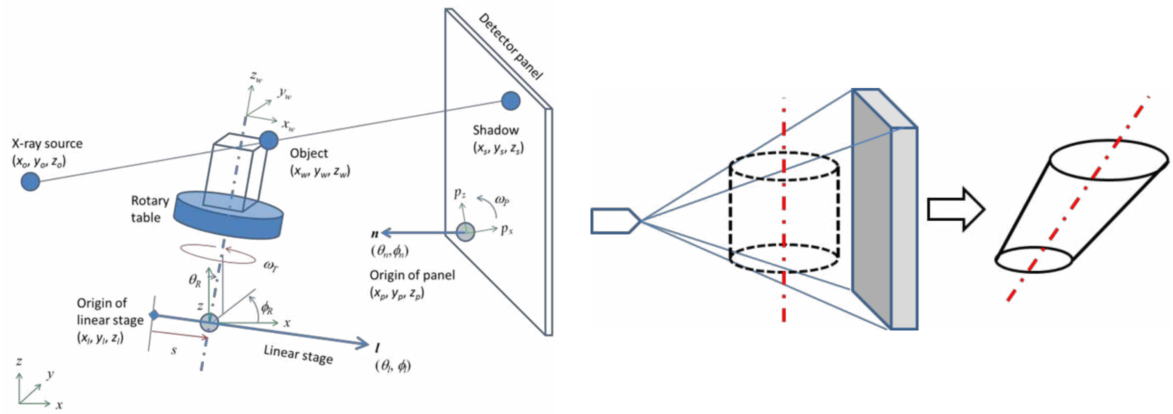


Fig. 4 Length measurement errors of the DXCT in directions.



a) Kinematic model of X-ray CT system.

b) Measurement volume deformation of an X-ray CT.

Fig. 5 Kinematic model and measurement volume deformation to be evaluated on DXCT.

Figure 6 shows the experimental setup of the evaluation of the dimensional measurement performance of an X-ray CT system. The calibrated artefact is measured, and the deformation of the measurement volume is estimated as shown in Fig. 7. In the series of the experiment, the stability of the system in a half month was also evaluated[2].

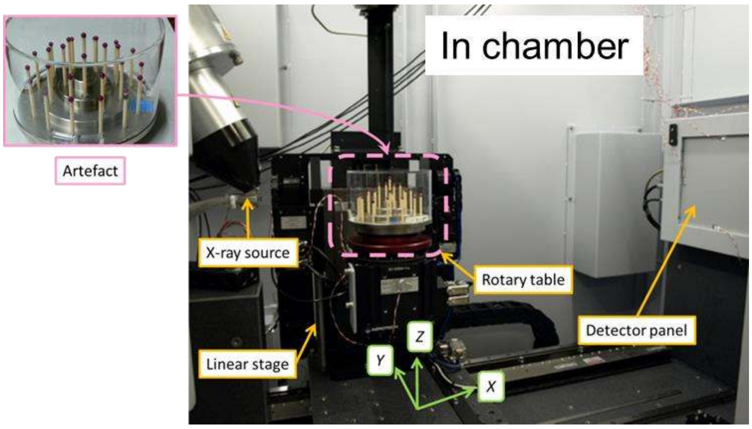
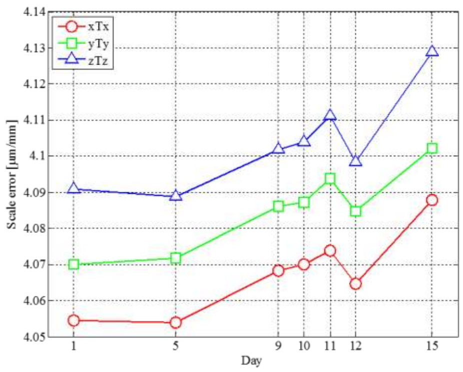
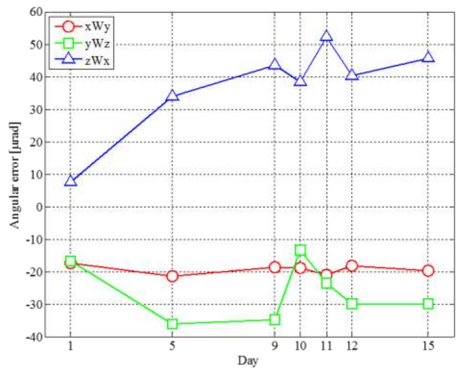


Fig. 6 Experiment setup for dimensional measurement performance evaluation.



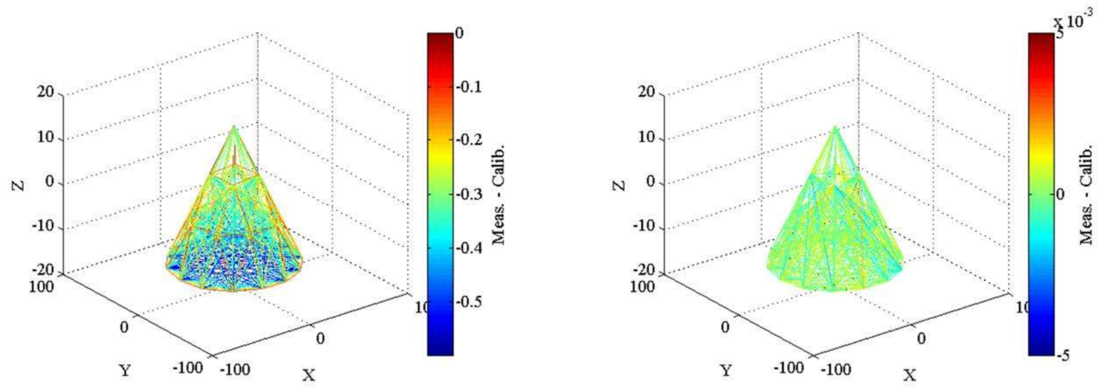
a) Scale errors in X, Y, and Z directions



b) Angle error between X, Y, and Z axes

Fig. 7 Deformation of the measurement volume of the X-ray CT system.

Figure 8 a) shows the length measurement error in directions without any compensation. As predicted from the data shown in Fig. 7, the system with no compensation has large measurement error. Figure 8 b) shows the measurement performance after applying proper compensation. The length measurement errors in directions are improved less than 2 µm, and the anisotropic deformation of the measurement volume is significantly reduced.



a) Without compensation. Length measurement errors in directions: up to 600 µm for 120 mm length.

b) After perspective deformation compensation. Length measurement errors in directions: up to 2 µm for 120 mm length.

Fig. 8 Results of length measurement error evaluations.

2.3 Industrial Standards

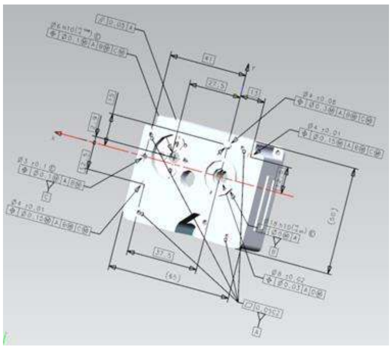
There exist several industrial standards on X-ray CT systems as non-destructive observation instruments, however, no standard for those as dimensional measurement instruments. One German guideline[3] describes the procedure to evaluate the performances of dimensional measurement of DXCT in accordance with the verification manner for tactile CMMs (ISO 10360-2), but the evaluation items in the guideline is controversial in ISO community. Now, ISO TC213/WG 10 is discussing the evaluation procedure for DXCT as coordinate measuring systems. The authors participate the development of the international standard. In 2017, the first step of the standardization, new work item proposal, has been done. In the years ahead, the detail of the evaluation: evaluation items, methods and artefacts to be used for the test, will be discussed and embodied.

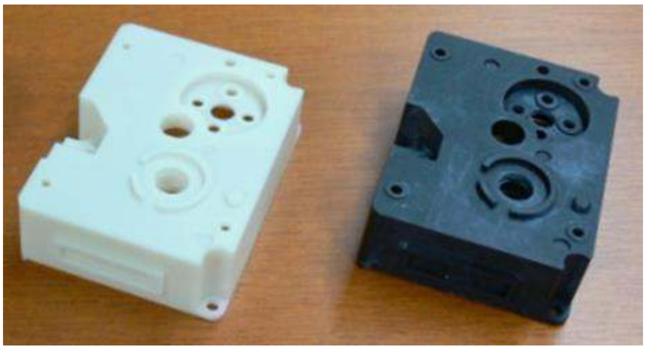
3 Application

3.1 Product inspection against 3D-CAD

One advantage of using DXCT is the test efficiency GD & T validation. Using tactile CMMs or optical CMSs, the operators have to change the orientation of the workpiece to be inspected or the instrument to be used to measure whole over the surface of the workpiece. Moreover, several local area on the workpiece surface cannot be measured because of the lack of accessibility of the sensor (probing system) or large noise caused by the optical phenomena. On the other hand, DXCT can measure whole volumetric data of the workpiece within one orientation setup and extract the surface of it. After the workpiece surface extraction, the all inspection items which are annotated in the CAD data are validated at once.

Figure 9 shows the example of the CAD data and practical workpieces to be validated against the annotations in CAD model. The workpieces are made of plastic of different colors. The workpieces are measured using several optical CMSs and DXCTs by respective participants of the comparison measurement. Figure 10 a) and b) show the instruments used by the authors for the comparison.

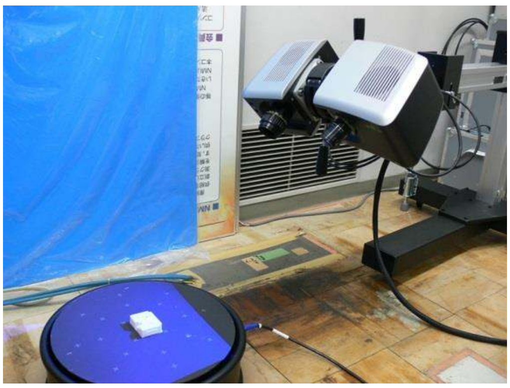




a) CAD of a product b) samples of the plastic product

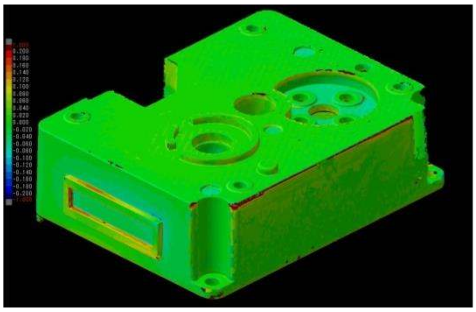
Fig. 9 Practical product design and GD&T to be validated.

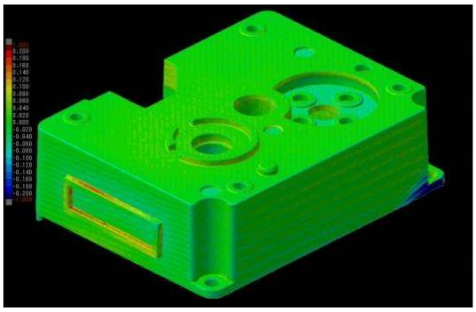
Figure 10 c) and d) illustrate the measurement results on the black workpiece shown in Fig. 9 b) using the optical CMS and DXCT respectively by the authors. Instead of listing the results of GD & T validation, the deviation from the CAD surface to the corresponding measured point cloud are shown as the color map; which means the profile of the surface. Without the stitching operation, the DXCT measures data comparable to the optical CMS. In addintion to that, the DXCT measures corner edges of the workpiece more precise than the optical CMS.



a) Optical CMS

b) DXCT





c) Measurement result for the black workpiece using the optical CMS

d) Measurement result for the black workpiece using the DXCT

Fig. 10 Comparison measurement using optical CMS and DXCT.

Acknowledgements

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