

DEVELOPMENT OF DIMENSIONAL X-RAY COMPUTED TOMOGRAPHY

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Abstract:

Recently, a dimensional X-ray computed tomography system that is capable of dimensional measurements is strongly waited because the realization of dimensional measurements for outward forms and inward forms on dense spatial points in short time duration remarkably simplifies and accelerates production loop. However the obtained image of the XCT describes the structure clear and in great detail, the realization of the dimensional metrology by the XCT is not simple.

National metrology institute of Japan have been continued the performance test using gauges that includes the gauges proposed in ISO10360. The magnification variation correction is carefully introduced and that the maximum deviation of less than 5 μm is shown to be possible by the measurement of the forest phantom of 27 sapphire balls whose locations are calibrated by the coordinate measuring machine.

Keywords: X-ray Computed Tomography, Dimensional Measurement, Phantom, Industrial Standards

1. INTRODUCTION

Industrial X-ray computed tomography (XCT) is widely used these days in the field of non-destructive inspection (NDI) of various products in wide industrial fields. Recently, a realization of an XCT system that is capable of dimensional measurements, i.e. the dimensional XCT system (DXCTS), is actively studied[1] because the realization enables non-destructive dimensional measurements of outward forms and inward forms of the work piece on dense spatial points in short time duration and it remarkably simplifies and accelerates production loop.

Obtained 3D image of the high resolution XCT describes the structure in the work piece clear and in detail. But such descriptive power of the image does not directly leads to the accurate dimensional measurements. Our needs of accuracy in dimensional measurements are micrometer level and we have to work and discuss in the level of less than image resolution, i.e. sub-voxel size of the XCT system.

In such level of measurement, deviations of calculation parameters from assumed mathematical definitions, which are introduced by geometrical misalignments of the apparatus, causes serious deviation of the position of the elements of the work piece from its original position. In addition, realization of the dimensional metrology by the XCT requires a capability of extracting models from the volume data, i.e. to detect surfaces and interfaces of the small segments in the object very accurate. The model extraction are strongly influenced by the material dependent nonlinearity between the transmission length and the

logarithm of transmitted X-ray intensity has to be corrected. There are many other factors that degrade the measurement accuracy of XCT such as noises caused by the scattering.

In the XCT system, a lot of imperfections are complicatedly coupled and it is not straightforward to derive the uncertainty from the algebraic technique. Therefore test methods and the traceability of the 3D metrological capability of the DXCTS is very important.

National metrology institute of Japan has been continued performance tests using several gauges proposed in ISO10360.

2. MEASUREMENT OF DEFORMATION

2.1 Specifications of the XCTS used in this work

The XCT system used in this work is SMX-225CTS constructed by Shimadzu Corporation.

The specifications are as follows.

- Source type: Microfocus
- Maximum tube voltage: 225kV
- Maximum input power: 135W
- Image Detector: Flat Panel of size 200mm by 200mm
- Freedom of sample stage: 2 (along magnification and rotational axes)
- Environment of sample: Temperature control
- Rotation axis: High rotational precision <math><1\mu\text{m}</math>



Fig. 1 Photograph of SMX-225CTS

2.2 Measurement Procedure

Measurements procedure are as follows.

- i) Selection of the tube voltage and current.
- ii) Air and offset calibration.

iii) Selection of the distance between the source and the rotation axis and selection of the exposure time.

iv) Reference gauge whose dimension property is calibrated by the CMM system is measured.

v) The work piece is placed and measured and 3D volume data is automatically calculated by the XCT system.

vi) A software for visualization and analysis of CT data, VGStudio MAX2.1, is used to extract geometrical parameters of the observed volume data.

The procedure iv) is executed if necessary.

2.2 Description of Experiments

The forest phantom is used for the evaluation of the spatial distortions caused by misalignments of apparatus. From the measured volume data the positions of sapphire balls are obtained. The forest phantom is used with the plexiglas cover on to avoid the damage on the fragile styli. Red balls are precision sapphire balls of 5mm diameter fixed on the alumina shanks and are arranged on the low expansion metal alloy. The positions of the balls are calibrated by CMM off line.



Fig. 2 Photograph of the forest phantom

The positions of 14 balls on the lowest level of the phantom are measured by XCT system for several vertical position of the phantom following the measurement procedure in previous chapter. Distances of 91 ball pairs are calculated and their average are plotted against the vertical position in Fig. 3.

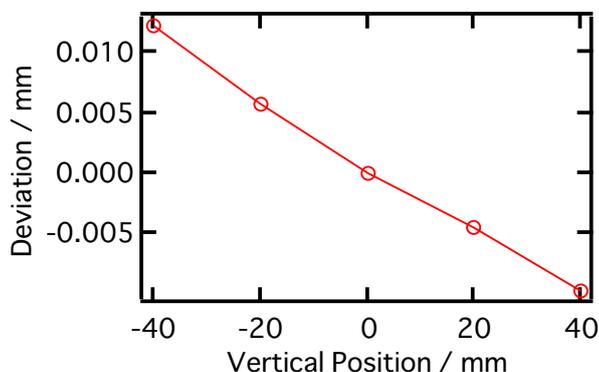


Fig. 3 Averaged deviation of lowest level of the forest is plotted against the vertical position.

Clear proportional relationship of the deviation against the vertical position of the 14 balls is observed.

The positions of all 27 balls are measured to evaluate the spatial distortion of measurement space. Distances of 35 ball pairs are calculated and a simple comparison is plotted in Fig. 4.

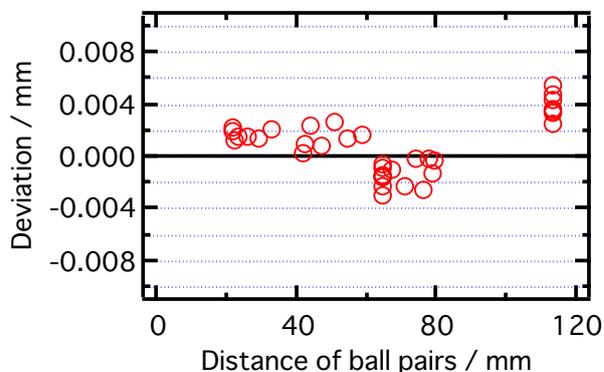


Fig. 4 Deviation of measured ball-pair distances from the reference values are plotted against the distance of ball pairs.

In this case, width of the distribution is about 10 μm and there are big discrepancies in data for longer distances.

3. DISCUSSION

Following the discovery in the Fig. 3, assuming that the magnification is proportional to the vertical position, distances are manipulated so that the horizontal positions of the balls are multiplied by unity plus factors that is proportional to the vertical position of balls and new deviations of distances of ball pairs are obtained. These are plotted in the figure 5. The gradient of the factors is adjusted so that the distribution of deviation becomes small. In this case, width of the deviation decreased down to less than 5 μm .

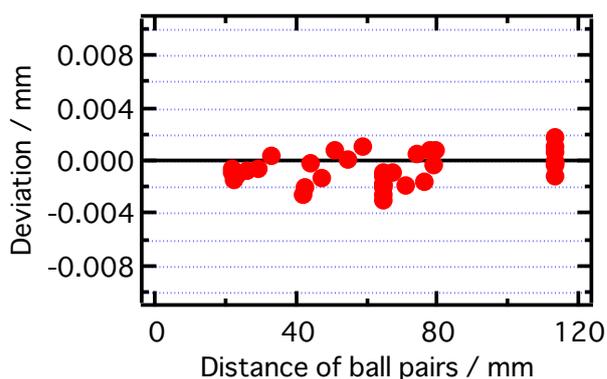


Fig. 5 Corrected deviations

The gradient of deviation against the vertical position in the figure 3 and the gradient used for the correction in the figure 5 are different.

This situation can be explained by the cause of change of the magnification as follows.

The magnification change can be caused by the tilt angle of the detector, the tilt angle of the rotational axis of the sample table and the tilt angle of the vertical travel of the

sample table if the major misalignments are considered. In the 14 balls experiment for the figure 3, all the three tilt angles have to be taken into account. In contrast in the 27 balls measurement for figures 4 and 5, the tilt angle of the travel of the sample stage is excluded. So the gradients can be different.

4. CONCLUSION

In this work it is shown that the deviations of horizontal distances from the reference values are proportional to the vertical position of the sample table. Also it is shown that the correction of magnification proportional to the vertical position of the detector leads to decrease in the width of distribution of the deviation of the ball positions of the forest phantom.

Further evaluation by the careful combination of experiments using gauges would leads to the separation of the misalignment and would leads to good uncertainty of dimensional measurements.

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