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Measurement and modelling of thermal loads in industrial CT scanner

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Abstract

X-ray computed tomography (XCT) is rapidly becoming the measurement tool of choice in a wide variety of industrial sectors where commonly used measurement techniques aren't optimal, typically when internal features of parts / assemblies need to be inspected. There are several key limiting factors when XCT is used as a metrology tool, such as relatively long measurement time, problems related to measurement of multi-material components, or insufficient energy to penetrate high-density materials while maintaining high resolution. One of the largest issues is the question of traceability of measurement results; due to very large number of influences on measurement uncertainty, it is currently not possible to establish a classical uncertainty budget and declare a priori measurement uncertainty of XCT results.
Influence of temperature on dimensional measurements is well known, and is usually relatively easy either to correct it, or to calculate its influence on the uncertainty of measurement. However, a typical industrial XCT scanner poses additional challenges: having several heat sources in a thermally well-insulated chamber and having a metrology loop in which thermal displacements cause several different errors. In this paper, we discuss one possible approach to this problem which is based, first and foremost, on extensive temperature measurement of the entire XCT metrology loop. These results are then used as ground truth for verification of simulation models, based on Finite Element Analysis (FEA), needed to establish temperature and displacement fields of XCT scanner geometry for the entire range of usable X-ray power levels. Finally, temperature measurements and FEA results are also used for verification of a simplified analytical model which could be useful in robust expression of measurement uncertainty.

Keywords: Accuracy, Dimensional, Measurement, X-ray computed tomography

1. Introduction

Defining thermal influences in an XCT scanner should begin with a systematic approach to measurement of temperature in various parts of XCT metrology loop. In order to acquire reliable results, preliminary investigation was made using a thermal imaging camera while X-ray power was kept at 45 W (Figure 1).

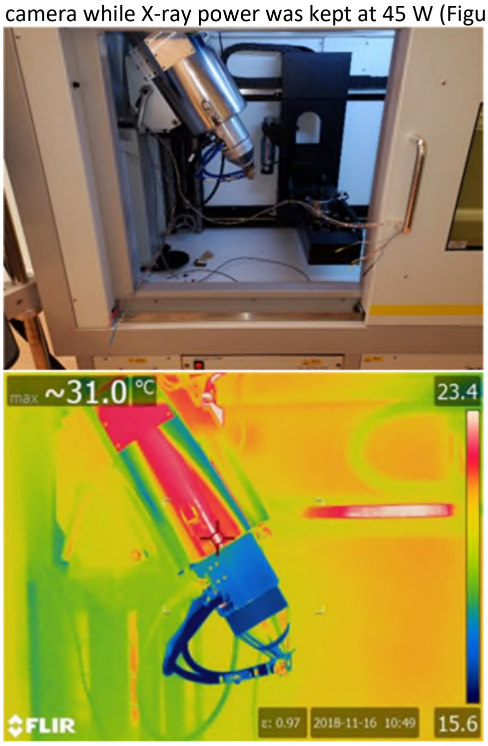

Figure 1. Image of X-ray source assembly (top) and its thermal image (bottom).

While this method couldn't be reliably used to measure absolute temperatures, it did provide valuable insight into existing temperature field distribution. Based on this, eight thermistor probes were traceably calibrated (U = 10 mK, k = 2) and placed at locations within the XCT scanner cabinet shown in Figure 2.

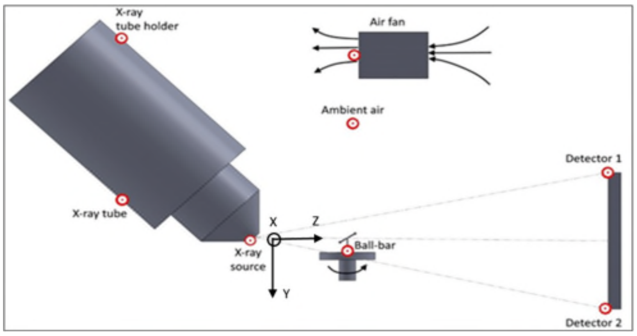

Figure 2. Schematic representation of the XCT scanner and location of installed temperature sensors.

Acquisition of temperature measurement using these sensors, performed over a time period of approx. 2 hours at X-ray power of 45 W, is shown on Figure 3. Measurement results clearly show significant variation of temperature, especially at the X-ray source and X-ray tube assembly. This change of temperature results with thermal expansion of the X-ray source and tube assembly, which in turn changes the position of the X-ray focal spot relative to the measurement object and the X-ray detector. Since these relative positions create the metrology loop, any undetected change has direct consequences on the accuracy and measurement uncertainty of XCT results.

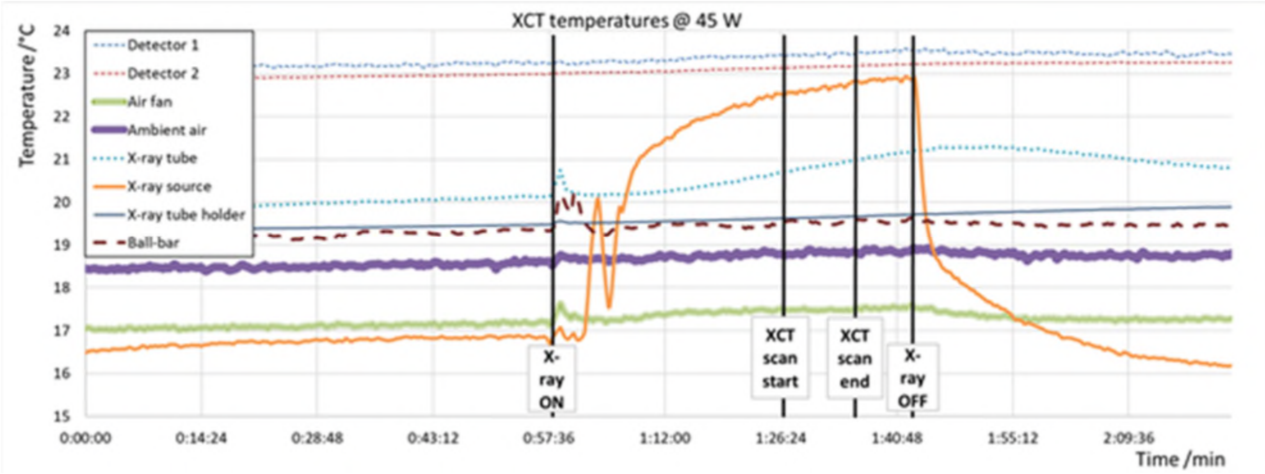

Figure 3. Temperature measurement results for 45 W X-ray power level.