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Towards metrological computed tomography at METAS

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Abstract
Industrial computed tomography (CT) is increasingly used for dimensional characterisation of workpieces. Therefore, the Federal Institute of Metrology METAS launched a project to develop CT metrology in Switzerland and satisfy the demands of the local industry. The metrology CT system, that is currently developed and built at METAS, is presented.

dimensional metrology, computed tomography, cone beam CT, helix CT, 9DoF metrology, thermal management

1. Introduction

Industrial computed tomography (CT) is used for non-destructive testing for more than 30 years [1]. In recent years, the method is increasingly employed for dimensional characterisation of workpieces. Besides providing fast acquisition of a large number of dimensional measurements, it is capable of measuring geometries inaccessible by tactile or optical methods, i.e. geometries that are either too small or internal. Especially the advent of additive manufacturing, such as 3D printing, renders CT indispensable for quality control. Yet, many metrological aspects, such as traceability and determination of measurement uncertainty, are still under intense research [1].

The goal of the METAS CT-project is to gain competence in the field and develop a custom CT system complying with metrological requirements. It is targeted to the needs of Swiss industry, thus focusing on small parts with geometrical features down to a few micrometres. The system, built from the most expedient components, includes air bearing stages for precise positioning of sample and detector and allows for circular and helical scan trajectories with magnifications up to 200. In particular, the system will be equipped with several measurement devices in order to accurately determine the 9 degrees of freedom defining the geometry of the whole CT system continuously. The system is built into an air-conditioned, walk-in radiation-shielded cabin. All heat sources are thermally managed to minimize drift. Eventually, the custom setup leaves room for future developments.

An overview of the system components, the positioning system and the thermal management, all of which are being implemented at the moment, is presented here.

2. METAS metrology CT system

2.1 Overview

Figure 1 shows a photograph of the walk-in radiation-shielded cabin. It has a floor space of 2 m x 3 m and is designed to shield X-ray energies up to 220 kV. Air circulation and temperature stability are ensured through direct connections to the in-house air conditioning.

As shown in figure 2, the CT system consists of an X-ray tube, a rotary stage, 3 linear positioning axes and a digital flat panel detector. A sub-microfocus X-ray tube (XWT-190-TCNF, X-RAY WorX) with a JIMA resolution down to 0.5 µm is employed. The maximal acceleration voltage and target power are 190 kV and 50 W, respectively. To capture radiographies a digital flat panel detector (1611 CP3, Perkin Elmer) with a pixel pitch of 100 µm and a pixel matrix of 4000 x 4000 is used.

The system aims for high-resolution, which entails the drawback of low X-ray intensity and detector efficiency. To address this problem increased exposure times and, thus, long scan times have to be taken into account. Therefore, the long-term stability of the system is crucial and will be addressed in the following.

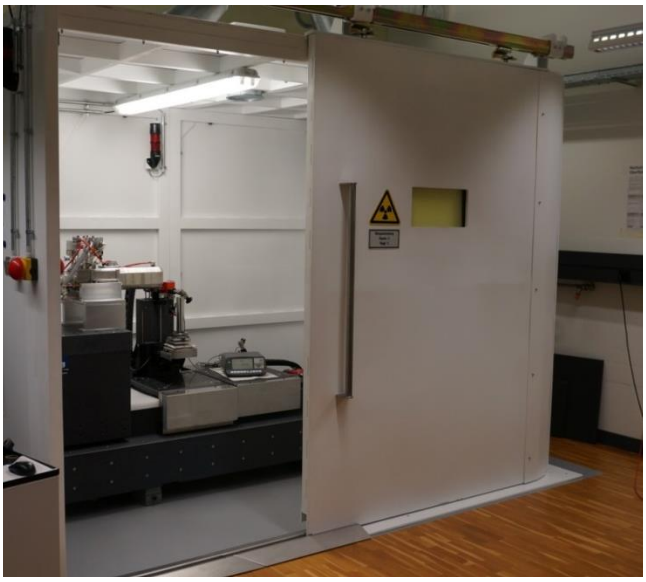

Figure 1. Walk-in radiation-shielded cabin at METAS.

2.2. Positioning system

A typical CT scan consists of a circular trajectory with the axis of rotation normal to the beam axis. The position of the source (X-ray tube) relative to the object and the detector is thereby crucial to determine the magnification as well as deviations from the ideal CT geometry [1], which is characterized by 9 degrees of freedom. The focal spot size, i.e. the JIMA resolution of the x-ray tube, would permit a smallest useful voxel size of about 0.5 µm. Therefore, the positioning system that

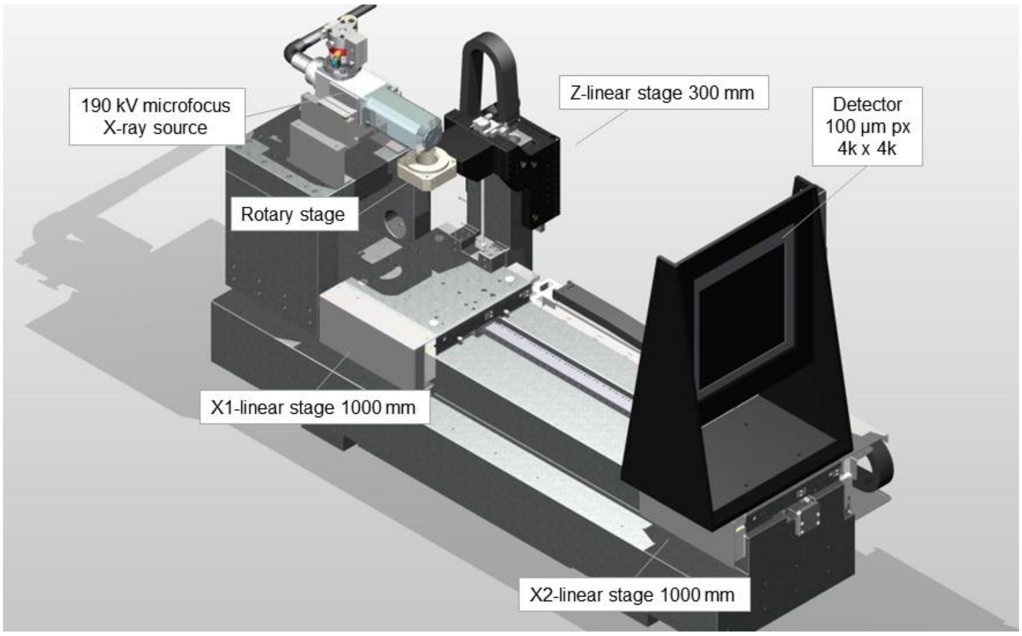

Figure 2. Metrology computed tomography system that is currently implemented at METAS.

implements the scan trajectory is required to position to about 0.2 µm. Major sources of error typically are due to positioning and drift [1].

The positioning system consists of three air-bearing linear axes and one rotary axis built by LAB Motion Systems (see figure 2). The system can realise source-object and source-detector distances of 0 mm to 1000 mm and 400 mm to 1400 mm, respectively, using a single linear guide, resulting in nearly perfect coaxial displacements. Furthermore, the object can be rotated and vertically displaced by 300 mm. The vertical axis is used for helical scan trajectories [2] and also to withdraw the object from the beam. In order to increase the stability of the system, it was decided to implement only a minimal number of positioning axes. The current concept leads to a rather high beam axis, about 700 mm above the X-bearing, which makes the system prone to pitch and roll errors of the two X-carriages. The measured mechanical error motions of the linear axes were within ± 3 µrad angular and ± 1 µm translational error. If, uncorrected the sample can be consequently positioned within about 4 µm, using the built-in linear encoders in the stages. Therefore, the linear encoders will only be used as a starting point for further position measurements and corrections. Whereas repeatable errors will be corrected using look-up tables, non-repeatable ones will be monitored by additional measurement systems such as laser interferometers and home-built straightness sensors.

2.3. Thermal management

One of the major influences in dimensional metrology is temperature. The workpiece needs to be close to the standard reference temperature of 20 °C, and for the measurement system small temperature gradients and drifts are required. In our setup heat sources, such as motion controllers and power supplies, are placed outside the radiation-shielded cabin whenever possible. The remaining two major thermal sources are the X-ray tube and the flat panel detector, each dissipating about 100 W. Only managed by the air conditioning this would lead to a rise in temperature of about 3 °C. Thus, the main part of the generated heat is removed by water-cooling systems.

The target and the coils of the employed X-ray tube are equipped with water-coolers. Only about 1% of the e-beam energy incident on the target is turned into X-rays, whereas 99% are converted into heat [3]. Since the power density in the focal spot is very high, thermal energy is potentially transferred to the workpiece. Preliminary measurements show temperature changes in the order of several degrees for source-object distances of a few millimetres at 100 kV and 20 W target power. The effect highly depends on the sample size, distance, material and airflow. Appropriate measures are planned for mitigation, e.g. forced airflow and filters.

Concerning the detector, the read-out electronics generates most of the heat. We have designed a detector enclosure that shields and actively cools the detector electronics. This has the further advantage that the pixel sensitivities are more stable.

Any residual heat will be monitored using a large number of temperature sensors, whose output can be used for a final drift correction. A temperature stability below 0.2 °C at the workpiece position is intended.

3. Conclusions and outlook

A first preview on the METAS metrology CT system was given. It features a sub-microfocus X-ray tube, an air bearing positioning system, and a digital flat panel detector. Special attention is paid to the positioning accuracy as well as to the long-term stability of the system. Both are crucial for high-resolution and high-accuracy scans. Once positioning errors are measured and corrected, effects such as beam hardening, that still limit the accuracy of metrological CT scans and are hard to compensate for [4], will be studied. Future work will also include estimation of the measurement uncertainty as well as establish traceability.

References

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