Computed Tomography at BAM –
From High Energy Technique to nm Scale

Uwe Ewert
BAM, Federal Institute for Materials Research and Testing, Unter den Eichen 87, 12205 Berlin, Germany

Abstract
BAM has been working in the field of X-ray computed tomography (CT) since more than twenty five years and several scanners were developed from LINAC based large scale tomography down to synchrotron tomography with crack detection in the nm region. CT has been applied recently for dimensional measurement of industrial products, which cannot be accessed by mechanical and optical systems. The comparison with measurements of coordinate measurement machines (CMM) yields information on accuracy and tolerances. New mobile systems were developed for inspection of industrial components which cannot be brought into laboratories. Non destructive cross sections were measured of welded pipes in primary circuits of nuclear power plants. A gantry tomography was constructed for inspection of fiber composite based aircraft structures. New metal matrix composites for high yield aircraft turbines were inspected with synchrotron CT after fatigue tests. Crack fields with openings in the nm scale were detected by refraction enhanced synchrotron CT. First applications of THz-CT are described.

1. Introduction

Several tomographic scanners were developed and are in use at BAM (see Fig. 1):
- high energy CT, based on mini-focus 450kV X-ray tube, Co-60 source and a 12 MeV electron linear accelerator.
- micro-focus laboratory CT units from 100 kV transmission type X-ray tube up to a 320 kV bi-polar micro-focus X-ray tube.
- Synchrotron CT in the energy range from 5 to 90 keV with high resolution detectors and optional magnification by asymmetric Si-crystals at the Berliner Synchrotron facility BESSY.

The presently used detectors are mainly flat panel detectors with different kinds of scintillators; cooled 16 Bit CCD-cameras coupled to a scintillating screen and more recently highly shielded line detectors for precision CT of single slices.

The recent applications are integrity of electronic components, characterization of filter media for chemistry, non-destructive evaluation of the corrosion process in chloride contaminated mortar.

Fig. 1: Parameters of the developed and used CT scanners at BAM
2. High energy CT

The largest CT scanner at BAM consists of a linear accelerator (LINAC) with the energy of 12 MeV, a manipulation system (translation and rotation) for objects of up to 1 European ton and different detection systems for 2D and 3D tomography. It can be also used with Co-60 or a 450 kV micro focus tube. The CT scanner is located in a two story basement laboratory. Figure 2 shows the test of an aircraft wing.

The LINAC CT is applied for large components as concrete structures, chemical reactors and other heavy components. It can be used for objects with a maximum thickness of about 350 mm steel equivalent.

3. Application of medium scaled CT systems

Several CT scanners are installed (Fig. 1) for inspection of small and medium sized industrial objects. Fig. 3 shows the CT image of a gas filled capacitor with a gas leakage. Different objects of aircraft, car and electronic industry were investigated for quality assurance and improvement of the production reliability.

4. Measurements of dimensions by CT

The ability of Computed Tomography for measurement of dimensions is well known since its first application in the 70ties. Nowadays the accuracy of CT could be significantly improved and the modern scanners can be produced in a series with relatively affordable costs. This makes the CT technology interesting as NDT and touchless measurement tool for dimensions, and especially, for inner dimensions which cannot be accessed by mechanical or optical tools. Prerequisite for the CT application is the accurate validation of the measurement procedure in comparison to coordinate measurement machines (CMM) and the present standards for determination of accuracy parameters with measurement systems. A new generation of multi sensor CMMs combines the CT operation with optical sensors and tactile probing. However, an important aspect of all coordinate measurements is the traceability of the geometry information obtained. To achieve traceability, several standards have been developed in recent years by PTB (the German national metrology institute), BAM (the German national material testing institute) and partners, within research and industrial projects. Material standards with high information content are a sphere calotte plate made of zerodur and a sphere calotte cube made of titanium, which provides 2D or 3D information for CT system testing and correction, respectively. The following parameters have to be determined: Sphere distance error (SD), probing error size (PS) and probing error form (PF). This has been performed by parallel measurements of calibration objects and real test objects with high energy CT, micro CT and CMMs. Measurement differences are visualized by color coding (see Fig. 4).

5. Mobile CT inspection

For industrial objects as bridges, pipelines and aircrafts, which cannot be brought to the laboratory, mobile CT scanners were developed. They are typically based on the planar tomographic design. The first applications are qualified by third party organizations for sizing of planar defects in nuclear power industry and aircraft industry.

5.1 Mobile CT for application in nuclear power industry

The mechanized mobile tomographic system “TomoCAR” (Tomographic Computer Aided Radiometry) was
developed first for inspection of circumferential welded seams of pipes [1-3]. It consists of the manipulator based position control of an X-ray tube in front of the region to inspect and a Digital Detector Array (DDA) behind it (Fig. 5). Several hundred radiometric projections in small angle steps are acquired. The tomographic reconstruction allows the three-dimensional (3D) representation of the material structure and included flaws. This is equivalent to a metallographic cross sectioning. It allows the reliable detection of planar defects with openings larger than 25 µm by subpixel resolution due to the achieved high signal-to-noise ratio of the used CdTe DDA.

TomoCAR was successfully qualified as the result of a German pilot study on the basis of the ENIQ guidelines (European Network of Inspection and Qualification) for application in the nuclear power industry. TomoCAR has been used for quantization of planar flaws several times in different nuclear power stations in Germany and Switzerland.

5.2. Mobile CT inspection of aircraft components

The TomoCAR design was modified for in situ inspection of large aircraft components under production conditions. A gantry gate based planar tomograph was constructed and tested for inspection of the integrity of large flat panel components (fig. 6). CFRP panels (Carbon Fibre Reinforced Polymers) of aircrafts of up to 3 x 9 m size were inspected. The integrity of imbedded stringers has been successfully tested. No alternative NDT method with similar detection rate has been found up to now. The technology was tested and qualified by the Airbus company. Different trials were performed to prove the finding rate of cracks in embedded stringers. The test sample shown in fig. 6 was a spherical panel of a vertical tail component of a plane. At both ends of the sample, 87 positions were defined and measured (marked in yellow in Fig. 6). The total length of all measured areas amounted to about 14 m.

Figure 7 shows the result of two planar reconstructions of embedded stringers. The black/white frame lines in fig. 7a, b mark the geometrical shape of the T-stringer in the embedding CFRP environment. The white stringer tip was outside the CFRP panel and the grey one inside, that means embedded. The two black indications in Fig. 7a show the adhesive connection of the stringer to the basic CFRP panel.

The stringer foot is visible as “roughness”, indicating a horizontal line with white end points. Fig. 7b shows a stringer cross section with a crack.

6. Synchrotron CT

Small angle refraction provides information on inner surfaces, as e.g fiber debonding, micro porosity and micro cracks [4]. The synchrotron refraction CT has been applied successfully to characterize fiber composites and ceramics. Fig. 8 shows the principle of the measurement. The radiation geometry is based on a set of two single crystal silicon plates. The first one decouples a parallel beam of a special frequency from the white synchrotron radiation in a changed direction. The object to inspect is rotated in this beam. The second silicon crystal plate decouples all radiation which did not change the direction by diffraction or refraction to the silicon plate and is converted to a digital CT projection by the 2D detector. In the reconstructed 3D-CT images the crack
7. THz CT

The new THz technique is based on the materials inspection with electromagnetic radiation in the frequency range of about 0.1 – 10 THz. The radiation penetrates non metallic and non conducting materials as ceramics, plastics and some composites (e.g. glass fiber reinforced). It can be applied for spectral and spatial inspection. Besides the well known applications for security it has been applied for imaging of material structures and defects. Computed tomographic and topographic techniques were developed and tested for volumetric inspection of non metallic test objects.

8. Summary

BAM has developed several CT scanners from LINAC based large scale tomography down to synchrotron tomography with crack detection in the nm range. CT has been applied recently for dimensional measurements of industrial products, which cannot be accessed by mechanical and optical systems. The comparison with coordinate measurement machines (CMM) yields information on accuracy and tolerances. New mobile CT systems were developed for inspection of industrial components in nuclear power and aircraft industry. Non destructive cross sections were measured in welded pipes. A gantry based tomography system was constructed for inspection of fiber composite based aircraft structures. New metal matrix composites for high yield aircraft turbines were inspected with synchrotron CT after fatigue tests. Crack fields with openings in the nm scale were visualized by refraction enhanced synchrotron CT. First applications of THz-CT were developed.

Acknowledgments

The author is grateful to the scientists of BAM, who contributed to the presented CT developments and applications. These are especially: J. Goebbels, Y. Onel, D. Meinel, B. Redmer, B. Ewers, M. Hentschel, A. Lange, B. Illerhaus, and B. Müller.

References