Computed Tomography of Large Components in Aerospace Industry

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Abstract. This paper presents two different CT methods for the analysis of very large components in aerospace industry.

Introduction

In aerospace the (X-ray) computed tomography (CT) gains more and more importance in non-destructive testing of objects made of advanced materials. The enormous size of the examined components represents a particular challenge for CT systems in this application area. The vast dimensions of the test objects result in the need for a stable acquisition process over the long measurement time, as well as to realize an efficient processing of huge amounts of data. Furthermore, due to the limited size of X-ray detectors special acquisition geometries with appropriate fusion of the raw data are required to provide a sufficient amount of information for a CT reconstruction.

In this paper, two different CT techniques for the analysis of very large components in aerospace will be presented. In addition to the acquisition geometries the associated algorithms for the pre-processing of the raw data are presented. At first the performance of the proposed CT approaches was tested using simulated data. The presented algorithms have then been integrated into a CT system for our project partner EADS in Bordeaux, France. The system was created specifically for the inspection of rocket (e.g. the Ariane 5) and other aerospace components. Therefore, actual data is available and will also be discussed in the context of this article.

1. Limitations of computed tomography as an inspection method

Computed tomography is a non-destructive testing method, which has now been used for decades and was right from the beginning in the focus of research and development. Therefore its limitations are continually redefined and expanded. In particular, the development of the components used for generating and detecting X-ray has great influence on the currently technically feasible.

The great advantage of this imaging method is the ability to map all internal structures of the test object in a three-dimensional representation. This image is acquired in a fully non-destructive and non-contact manner and contains a huge amount of valuable information. Not only defects such as foreign material inclusions or cavities can be reliably detected, it allows for a precise non-contact measurement of the internal structures, as well as material analysis of metals or composites (fiber orientation, fiber distribution and more.). This extreme versatility qualifies the CT as the optimal test method for a variety of applications, particularly in research and development of new materials. In this area in particular, the aerospace industry is one of the leading innovators.

They invest a large amount of resources in the development of very light and yet extremely durable materials. In later development cycles these materials are frequently used to build very large components, often in combination with metal parts. These components are usually made in relatively small numbers and it must be ensured that these components meet the very high demands on their reliability.

The CT is one of the essential inspection tools for this application, but some constraints on the use of this method need to be considered. Components with such large dimensions can only be inspected when a sophisticated mechanical system for the handling of the test object or the inspection system components is available. This system must be designed for large loads on the one hand and at the same time offer a high precision positioning over long distances. Systems, which combine all these qualities, usually are expensive and specifically engineered for a certain inspection task.

The large size of the specimen arises another problem: The radiation has to travel long distances through high absorbing materials. Therefore high-energy sources are needed, like conventional X-ray tubes with very high power, or alternative sources such as linear accelerators must to be considered.

The attenuation of the radiation must be captured entirely for the whole measuring field to enable a 3D reconstruction. To accomplish this, either a very large detector is needed or it is necessary to fall back on an alternative and specially adapted acquisition process. Some of these special acquisition procedures will be presented in the next section.

But high demands are not only made on the components of the data-generating system, but also the processing of this data requires a lot of computation power. This type of measurements produces large amounts of data and that data must be processed within a reasonable time. For storage, reconstruction and visualization of that data a reliable and efficient IT infrastructure is required. The long measurement times, especially for high-resolution measurements demand an outstanding stability and reliability for all involved system components.

2. Solutions for the practical use

A system that meets all the requirements above is the system for CT examination of very large components for the aerospace division "controle non destructif" of EADS Astrium Aquitaine at the compound near Saint-Médard-en-Jalles in France. It’s a several years old large machine setup, which was upgraded by Fraunhofer IIS with modern X-ray components and converted to provide new measurement methods (see Figure 1 & 2).

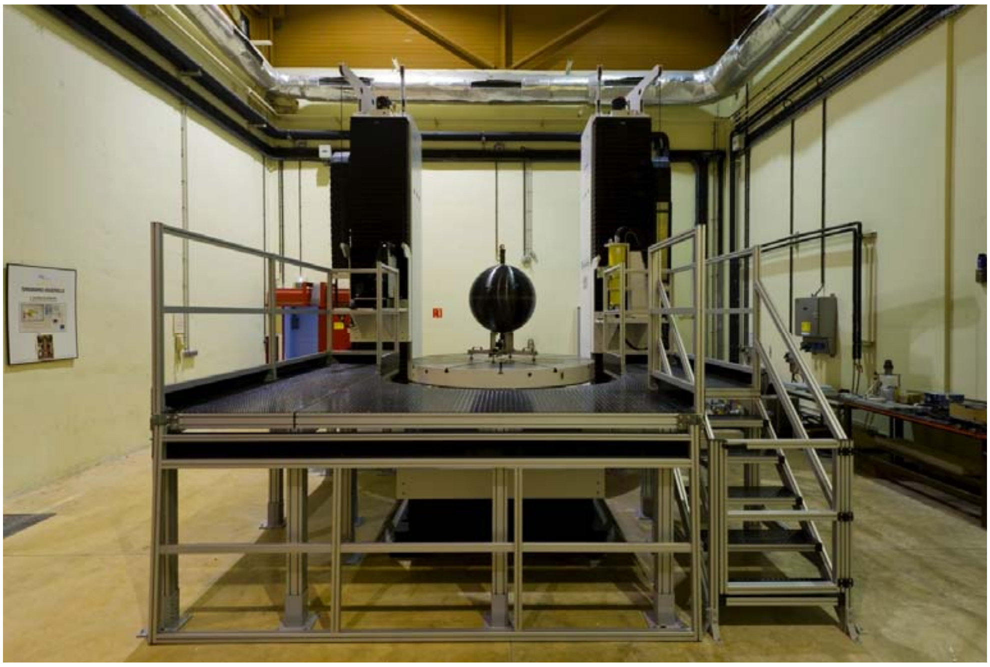

Figure 1: CT system EADS Astrium Aquitaine[1]

Important parameters of the system:

- Rotation axis for specimen
  - Self-weight: 1,5 tons
  - Load capacity: 3 tons
  - Diameter: 2,6 meters
- Linear axes
  - Positioning accuracy < 10 µm
  - Velocity up to 100 mm/s
  - Axis for specimen:
    - Orthogonal to direction of x-ray beam
    - Travel range > 3 meters
  - Vertical axes for X-ray tube and detector
    - Travel range 2,5 meters
- Components
  - PerkinElmer XRD 1621 Detector
    - 2048 x 2048 Pixel (200 µm resolution)
  - Yxlon Y.TU 450-D09 Tube
    - Up to 450 kV / 1500 W
- System parameters:
  - Source-detector-distance: 2,85 meters
  - Magnification factor for big turntable is ≈ 2

Figure 2: Loading the turntable. Visible in the back: the two towers of the manipulation system for detector (left) und X-Ray source (right) [1]

The system was optimized to provide a high resolution and to increase the flexibility of the overall system at the same time. A flat panel detector with a pixel size of 200 microns is used and the goal was to enable the machine to measure arbitrary objects with up to 2.6 meters in diameter and 2.5 meters in height at a constant magnification (approximately 2). The resulting reconstruction has a voxel size of 100 micron. Additionally a mobile second turntable has been introduced, which can be positioned entirely free on the large turntable and thereby the system is extended to include the ability to perform measurements at any desired magnification.

For a CT measurement a large number of radiographic images of a constant rotating specimen is acquired. To reconstruct an object with high quality (if possible without strong artifacts), it is crucial that the horizontal dimension of the object is completely imaged in each radiograph. If it's not possible to image the object completely at all or if it moves beyond the right or left edge of the measuring field during the acquisition, the object cannot be properly reconstructed from this incomplete data. Strong artifacts occur if the object is not fully captured horizontally.

Since the detector has a relatively small sensitive area (40 x 40 cm), it can only cover a very limited part of the specimen, which is not enough for an artifact-free reconstruction of large objects. Therefore it was necessary to look for ways to expand this measuring field.

Two options are presented in the following section.

3. Measuring methods

3.1. Measuring field extension by object translation

The method, which is applied for measurements of smaller objects using the small free-moving turntable, is a procedure that enables the extension of the measuring field by displacing the object (see Figure 3). Through a clever shift, additional radiographic images are acquired, which image the sections of the specimen outside of the cone beam measuring field (see Figure 3 II & III). These additional images can then be transformed in a post-processing step, and be attached to the central radiograph so that a merged projection is created, on which the object is completely imaged. As a result an artifact free reconstruction is possible (see Figure 3 IV).

Figure 3 illustrates the principle of this method. A 3-fold increase in the measured area is schematically shown as an example, but the method itself allows for more measuring fields.

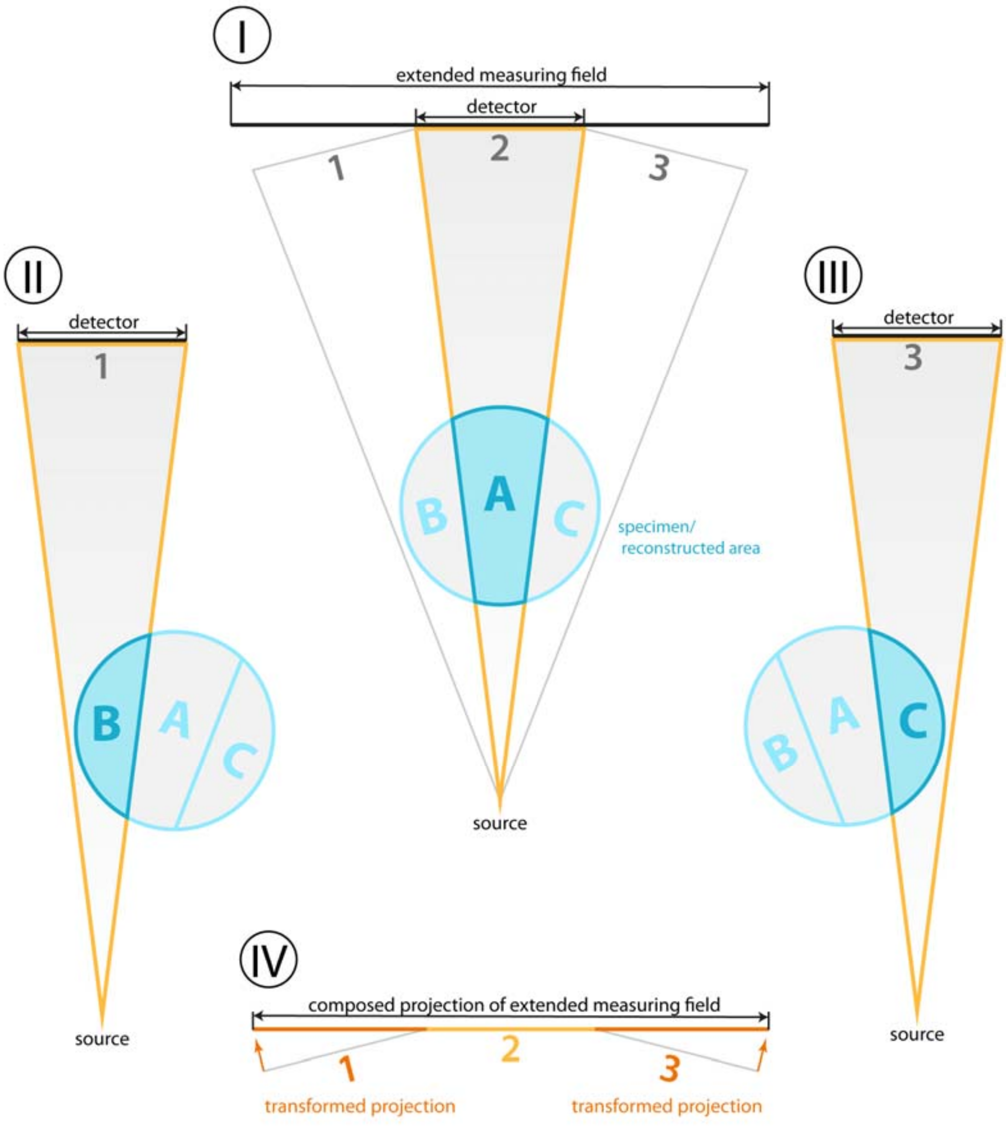

Figure 3: Measuring field extension by object translation

An additional challenge in the applicability of this method is the inability to displace the rotations axis in the direction of the tube. To properly position the object in the beam path, it is required to move the center of rotation on a circular path. This lack of movement can be compensated by an approximate transformation of the projection. However, this limitation results in a limited extension of the measuring field for this method. For particularly large objects a further method has to be used.

3.2 Translation-Rotation measuring method

This method allows the user to tomograph almost infinite large object. The only factors limiting the size of the specimen are the available space between the tube and the detector and the required travel of the object axis, which is orthogonal to the beam direction. This travel range must be greater than the sum of the diameter of the object and the detector width.

For the system described this maximum diameter of the object is 2.6 m.

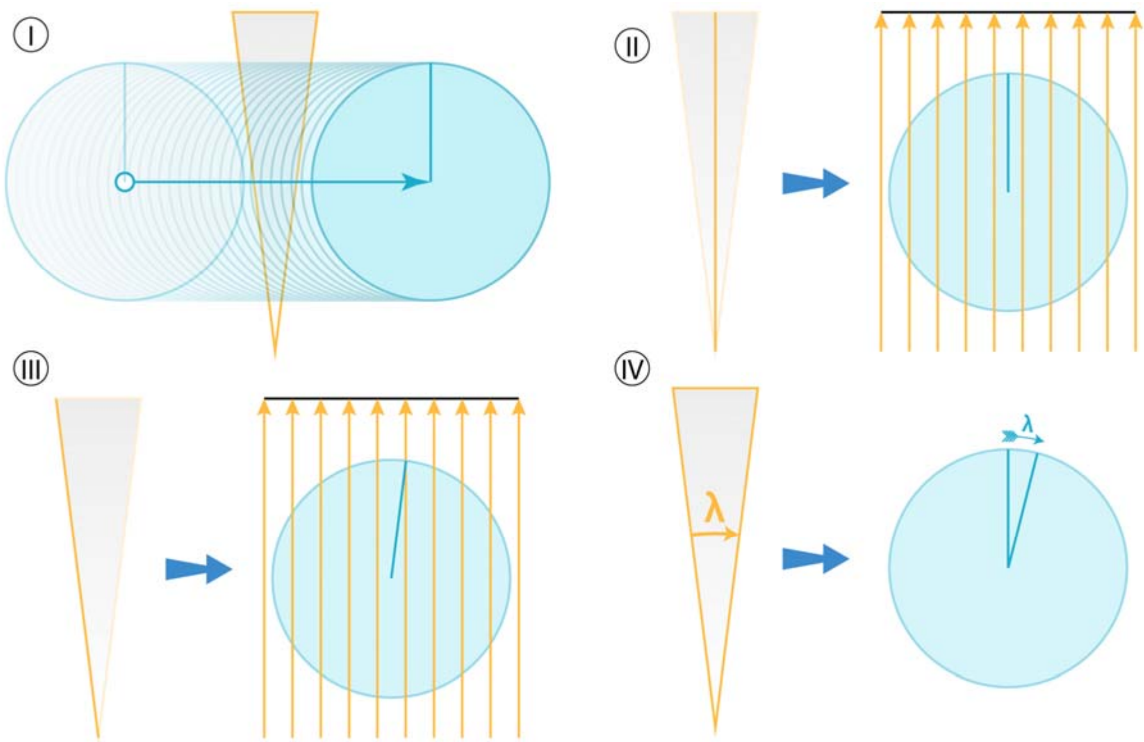

Figure 4: Schematic representation of the measurement process of a translation-rotation measurement

For this acquisition procedure we have completely different movement: the object is moved outside the radiation beam into the start position, then it is moved through the cone beam until it leaves the beam on the other side (see Figure 4 I). During this movement projections are acquired every time the object has traveled a distance, which is equal to the desired voxel size (see Figure 4 I). Then the object is rotated by the horizontal opening angle of the cone beam and then moved again through the cone beam. This is repeated until the object is rotated for at least 180°. With the acquired data it’s possible to perform a post-processing step, which is able to calculate projections that are suitable for an artifact-free reconstruction (see Figure 4I V).

This entire process is illustrated in Figure 4. The calculated projections are so-called "parallel cone beam" projections, because after the post-processing the beam in the

horizontal plane is no longer passing through the object like a fan beam, but in parallel. In the vertical plane a fan-shaped spread of the rays is still present.
This whole process is very similar to the known "CT scanners of the 2nd Generation " in medicine [2].

4. Further developments in the field of CT of large components

Fraunhofer IIS is working to optimize the methods described herein and further drastically shorten the measurement time while maintaining quality. Especially in the field of computed tomography with high-energy x-ray sources is an active area of research. A new test facility near Fuerth was put into operation, in which measurements using a linear accelerator as a radiation source can be performed. Energies in the range of several MeV can be achieved. Working with such high-energy sources is especially important for large objects made from high absorbing materials. [3]

In particular in the field of aerospace, there are often parts that cannot be transported or moved and thus the measurement is not possible in a conventional CT system. Therefore the Fraunhofer IIS explores the possibilities of carrying out on-site measurements. This is achieved through systems such as "robot-CT". In this system, the components required for measuring (X-ray source and detector) move around the object on arbitrary trajectories by using mobile six-axes robots or other manipulation systems. [4]

References

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