3-dimensional X-ray inspection of very large objects
600 kV Digital Laminography offers a solution

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Abstract
Testing large objects especially when 3-dimensional data is needed is still a challenge. There are three main obstacles in the process of acquiring 3-dimensional data of these objects. Due to the general planar geometry, it is not possible to penetrate the object in an axial Computed Tomography setup in all directions. Also due to the size of the object and the need of a sufficient resolution only a Region-of-Interest (ROI) can be scanned at a time. Furthermore, the material itself or the sheer amount of material denies penetration with conventional X-ray systems. Therefore a 600 kV Digital Laminography system was developed offering a solution for the above mentioned challenges in many cases. Contrary to axial CT, it is neither necessary to rotate the object nor to rotate the imaging system around the object.

Keywords: Computed Tomography (CT), Digital Laminography, automotive, aerospace, Large CT-Volumes, High energy X-ray

1. Introduction

In most industries the technical improvements leads to a higher complexity in the products. The result of this trend is a rising demand of high sophisticated test procedures. Computed tomography is already very successful as a test toll of small to medium sized products. Unfortunately not only small parts like turbine blade have to be tested but also very large parts from multiple industries. But testing large objects especially when 3-dimensional data is needed is still a challenge. However, there are more and more objects with a size up to several meters in two dimensions having a complex inner structure, e.g. aerospace parts made of composite material or parts in the automotive industry like car doors or hoods, or super-sized industrial ceramics used as protector against heat or abrasion. There are three main obstacles in the process of acquiring 3-dimensional data of these objects. Due to the general planar geometry, it is not possible to penetrate the object in an axial Computed Tomography setup in all directions. Also due to the size of the object and the need of a sufficient resolution only a Region-of-Interest (ROI) can be scanned at a time. The challenge is the unfavorable ratio between the total size and ROI. Furthermore, the material itself or the sheer amount of material denies penetration with conventional X-ray systems. Therefore a 600 kV Digital Laminography system was developed offering a solution for the above mentioned challenges in many cases. Contrary to axial CT, it is neither necessary to rotate the object nor to rotate the imaging system around the object.

The combination of the large size, high precision manipulation system with a high power X-ray source is the perfect solution for the investigation of large objects with planar geometry. Applying the principles of Laminography, even small spots of interest can be investigated throughout the entire object. In this particular case, this technology combined with a 600 kV X-ray system and state-of-the-art digital flatpanel technology opens a new field of application for Non-Destructive Testing of large objects.
In the following article we introduce the 600kV X-ray source and the implementation of digital Laminography for very large objects.

2. The 600kV X-ray source for large objects

A few years ago, when discussing CT of large objects, the only option has been the use of Linear Accelerators. The benefit of Linear Accelerators is the high energy which ranges into the two digits MeV range. But there are drawbacks to: First of all the high energy in itself leads to very high demands in the radiation shielding, reducing the flexibility of an installation and increasing the costs. Also the maintenance and legal restrictions for operating such a system are more challenging. In addition to that a Linear Accelerator lacks the flexibility everybody values in a X-ray tube.

Therefore we choose a 600 kV X-ray source which exceeds the traditional maximum kV range of X-ray tube of 450 kV. As standard X-ray systems the Y.MG605 has to focal spots, one 400 μm focal spot with a maximum power of 700 W and a 1 mm focal spot with a maximum power of 1500 W. Focal spot size according EN12543 with a 20% threshold.

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![Figure 1: Y.MG605 X-ray system for high kV applications](image)

![Figure 2: Load characteristic of the Y.MG605 600kV X-ray source](image)
Prior to using the 600 kV X-ray system we made a series of tests in order to have a better understanding of the limitation of the system. First we [1] tested the system using conventional X-ray film technology for an indication of the parameters. With a C5 film type, a Density of 2.5 and Focal spot film distance of 1000 mm we were able to reduce the exposure time for an 80 Steel sample from 60 min to 18 min. We transferred this knowledge to a digital flat panel application. The setup was a 100 mm Steel plate, the detector having a 400 µm pitch, the FDD 1330 mm, the magnification 2.2. With this setup the SNR\textsubscript{N} could be increased from 62 to 82 using 600 kV instead of 450 kV [1]. The improved the SNR\textsubscript{N} of 32% is one further step in acquiring high quality 3D data.

Figure 3: Comparison of a 600kV X-ray image with a 450 kV X-ray image [1].

3. Digital Laminography practice

3.1 Geometry and measurement methodologies

The movement of a Digital Laminographic manipulator is totally different compared to a conventional Computed Tomography system. In a typical Computed Tomography system the detector and X-Ray source are positioned in same high having a horizontal of beam. Also the center beam is always used in right angle to the plane of object and the detector. For recording measurement data, the detector will read out continuously during a full or half turn of object. In order to have a good image quality the number of projections has to be in the same magnitude as the length of the reconstructed volume in voxel. Therefore the object or a gentry has to be rotated continuously or in a “stop and go” mode.

When scanning large objects with conventional Computed Tomography, depending on the image reconstruction method applied, the image is either razed or disrupted from severe artifacts where penetration is lost. However some residual information might be available from areas with sufficiently penetration. This happened mostly if object has a planar structure. Most limited factor to use Computed Tomography is a large planar length preventing a rotation due to the fact that they will collide with either detector or source.

The Digital Laminographic measurement mode is the best choice for large planar objects. The penetration length of center beam depends on the angle to object plane. Possible angles typically range from 20° to 30° measured from the perpendicular vector of the plan. A larger angle generates a better slice resolution in object plane. At same time the penetration length will increased. At a lower angle the slice resolution is not as good, but there is also less material to penetrate. Limit case of 0° is a standard Digital Radiographic image with no slice
resolution in object plane and the shortest penetration length. Generally there are different types of Digital Laminographic measurement methodics possible. Linear or cross Digital Laminographic type requires a not as complicate manipulation of source, detector and object. But resolution is different in the X and Y axis of slice plane. Aiming for anisotropy of the resolution in the XY-plane we choose a circular Digital Laminography setup.

In a circular Digital Laminography setup Detector and tube are moving at a full circular trajectory with shift of phase 180°. The symmetry center of the trajectories of detector and tube has to meet the same geometry point of middle layer in every object plane during complete measurement.

The methodic of circular Digital Laminographic requires a complex movement of source and detector. For having a symmetric cone beam at relevant object area at every measurement position, the center beam of X-Ray tube has to turn up and down also turn right and left.
In the system we designed, we implemented the circular Digital Laminography trajectory by a patented transformation of our coordinate system. The vertical movement of the tube is realized by combination of a up and down movement together with a tilting. The horizontal moving is realized by turn detector and object plane in parallel. This Digital Laminography system is designed for object sizes with length of 1600 mm and height of 750 mm Object thickness depends on the density of material. Object weight is about 250 kilograms. Bigger objects also can apply by shift and flip over.

3.2 Measurement time and reconstruction

Typical measurement time of object volume 250 mm³ and voxel volume of 2048³ is about 5 to 10 minutes. Measure data volume is about 0.8 Gigabyte. The reconstruction runs by inline mode in same time range. Output data is presented by a voxel volume with 32 bit float. This volume can imported in standard 3D image processing software, which is used also for Computed Tomography results.

3.3 Laminography results

When analyzing the results of a Digital Laminography slice by slice in the direction of the X-ray beam they look like a conventional Computed Tomography scan. But due to missing areas in the Radon space the resolution and also artifacts deviates from results from conventional CT in planes perpendicular to the object plane. There artifacts from neighboring planes might occur and the images is more blurry. The excellence of Digital Laminography is to detect failures like cracks, inclusions, bubbles and structure abnormalities. It does not give the same detail visibility like conventional Computed Tomography but it comes close in many practical applications and surpasses Digital Radioscopy by adding the third dimension.
Conclusion

As to be expected a 600kV X-ray source exceeds the limitation of a 450kV source. It is up to the user whether he chooses to expand the maximum thickness of material to penetrated, the Signal to Noise Ratio or to save time. The challenge in the Laminography setup itself is how to handle large objects and how to manipulate the 600kV X-ray tube. The principle of the Laminography proves to be ideal for large objects due to the fact that compared to standard computed tomography it is not necessary to rotate the object. In addition to that the ratio between the size of the object and the scanned volume (ROI) is only limited to the mechanical handling of the object. Therefore it is possible to scan a small region with a high resolution in a much bigger structure. Our results show that small structures could be detected and their three dimensional location could be determined in objects which would be too large for conventional Computed Tomography.

References