Fully automated in-line 3D-CT inspection – example on the basis of an integration into an aluminum-casting production

Sven GONDROM¹, Thomas GÜNTHER¹
Ferdinand HANSEN², Frank JELTSCH²

¹Volume Graphics GmbH, Wieblinger Weg 92a, 69123 Heidelberg, Germany
e-mail: gondrom@volumegraphics.com, guenther@volumegraphics.com

²Volkswagen AG, Mecklenheidestrasse 74, 30419 Hannover, Germany
e-mail: ferdinand.hansen@volkswagen.de, frank.jeltsch@volkswagen.de

Abstract

Within the last years, 3D-CT has become more and more established for industrial use and lot of progress has been made in fast CT reconstruction. This enabled the design of CT systems performing a scan in less than 30 seconds. Therefore, the scan time of a fast CT system can be in the same range as the production time of a wide range of products, e.g. light metal castings. However, having overcome the hardware challenge does not mean that implementing an inline CT in production can be realized without having to overcome new obstacles. Performing a CT scan in such a short time results in a dramatically reduced number of X-ray photons used for reconstruction compared to a normal CT scan. This leads to a comparatively bad SNR in the reconstruction and so to a noticeably reduced contrast resolution. This loss in image quality even occurs when high power X-ray tubes are used. At the same time, the aforementioned tubes limit the spatial resolution due to their big focal spot. As a result of these physical effects, it is not sufficient to simply strive for an increased calculation speed in an existing standard inspection software in order to perform meaningful analyses and measurements within a shorter time frame. Instead, a fully automated in-line inspection software solution is needed, including automated pass/fail decisions and equipped with specially developed algorithms, which can deal with the bad SNR. Furthermore, use in an industrial setting necessitates for such a SW to be fast, scalable, repeatable and reliable as well. Finally, a reasonable approach requires that an end-user will be able to set up and modify the analyses and measuring plans by himself. Only then will an in-line CT become convenient and attractive enough to be accepted by industry for a wide range of use in a production environment.

Keywords: CT, in-line, light metal casting, automated evaluation, software

1. Introduction

The last few years, saw rapid development in the field of 3D-computed tomography (3D-CT), leading to a widespread and still growing acceptance and prevalence for this technology. Looking back on the recent rise of industrial CT it is not surprising at all, that there is a huge interest and a strong demand to apply 3D-CT as a powerful non-destructive inspection method also within a production environment. Doing so, however, one has to take into account, that the requirements in production are completely different compared to a laboratory CT setup. Therefore, it is necessary to adapt the inspection method to these special conditions.

2. 3D-CT in a production environment

About five years ago, there have been some initial test installations and a few pilot projects with the aim to transfer the well-known 3D-computed tomography from the laboratory to the production floor. The advantages of 3D-CT compared with the well-established 2D-inspection methods are obvious. 3D-CT delivers by far more information. This advanced technology not
only detects the defects and features of any given sample, but also delivers exact information about their size, shape and position within the probe. Thus, features can be classified much more accurately. Moreover, 3D-CT enables nominal-actual comparisons against CAD data, wall thickness analyses and in case of fiber enforced materials even the determination of the fiber orientation tensors and fiber densities.

With this manifold application spectrum, 3D-CT is ideally suited as a universal, non-destructive inspection method and this further explains the strong demand to use its advantages in mass production as well. Unfortunately, there are very different requirements in a production environment, compared to the use e.g. in a quality laboratory. In a lab, the pure scanning time of a 3D-CT may be around 30 minutes, usually followed by an extensive and time-consuming manual evaluation.

In contrast to this, a typical cycle time for the production of parts that are prone to be inspected with 3D-CT is in the range of 30 seconds. In order to ensure a 100% inspection not only the CT scan itself but also the automated evaluation of the CT data must be performed in the same, very short time frame.

As with any other imaging method, very basic physical principles cause a reduction of the image quality achieved in such a short cycle time, compared to results that can be achieved with the comparably long scanning times in a lab. Especially the signal-to-noise ratio and consequently the contrast resolution will decrease considerably; as well as the geometrical resolution. A reason for this is the reduction of detected, image forming X-ray photons when trying to achieve the dramatically reduced scanning time necessary. This reduction is due to the fact that commercial X-ray tubes deliver a limited photon flux and the sensitivity of available detectors is also restricted. Another limiting factor to keep in mind is that the power of an X-ray tube is directly linked to its geometrical resolution via its focal spot size, which results in a finite geometrical resolution of the whole imaging system [1]. As a consequence using better hardware to solve this problem is no real alternative since the technology used is limited by basic physical principles – something that thus far has not posed a problem since modern laboratory systems normally are already equipped with state-of-the-art X-ray tubes and detectors.

Instead, the analysis and evaluation software to be used has been getting the focus in recent years since this is the area where there still is potential to adapt to the conditions in production. In other words, one has to look for a software solution where not only the analyses are computed swiftly, but also precisely and insensitive against noise and occurring artefacts in the original scanner image.

The aforementioned pilot projects tried to deal with this by using a software solution where the analyses had been specifically developed and adapted to the respective inspection problem. Of course, this turned out to be a major limitation as the set-up of such a solutions proved to be very time consuming and expensive and turned out to be very inflexible on top.

3. Concept of a successful evaluation software

In order to deal with the described boundary conditions it is necessary that an inspection software for analyzing 3D-CT data provides very robust analysis algorithms. VGStudio MAX, the most comprehensive analysis solution for industrial CT data on the market today for example enables the user to adjust all kinds of analysis parameters to adapt to different image qualities. With such a software, it is possible to perform high-end defect detections, actual-nominal-comparisons, wall thickness analyses and even metrology and orientation analyses directly in production.
To make all these well-established analyses suitable for a fully automated inspection, the results of each analysis can be tolerated. The different results can be combined to come to final overall good-bad-decision, which Volume Graphics calls an “evaluation”.

To enhance applicability and acceptance, all provisionary steps are performed using the established and well-known standard software VGStudio MAX that has been used in quality labs for years. A macro recording functionality allows for the recording of complete measurement and inspection templates that are generated within the software with only a couple of mouse clicks. These macros are then transferred to the inline functionality of the software with very little effort. The fact that a user now is able to generate and adapt any given inspection template himself is fulfilling the most important prerequisite for the more convenient set up of an inline-inspection. An additional benefit of this “do-it-yourself” concept is the flexibility such an approach will offer. It is now so much easier to react on design changes of the part to be tested or even scan a completely different part with only little effort for the set-up of the inspection.

Aside from allowing adaptions and automations it is mandatory to also have a new, special analysis method for inline tasks, that will cover even those cases when robust standard defect detection algorithms fail, e.g. due to strong CT-artefacts like beam hardening, edge artefacts, partial volume effects or stripes due to undersampling. Such artefacts can easily accumulate especially when relying on very fast CT scans.

The best approach to deal with data sets described above in a serial inspection is to generate a kind of ‘virtual golden part’ out of a minimum number of scans that have been qualified as ‘good’. In a serial production, the minimum number to create a virtual golden part can be achieved normally within one or two shifts. Volume Graphics can offer to train a reference volume out of these multiple scans that includes the typical and specific artefacts of the given specimen. This „trained” data set allows conclusions – with a good statistical significance – about how the scan of a part should look like at any given area of interest and which deviations can be still considered “normal”. The trained attributes may be the reconstructed grey values or even more complicated features like fiber orientation.

A simple comparison of a new scan with the reference data set, which in fact is a full volumetric nominal-actual-comparison, can not only be computed very fast, but is also highly sensitive to the characteristics of production and by far less error-prone as standard analyses. That is why this kind of inspection has been identified as the method of choice for an inline-scenario.

Last but not least, an inspection software that is to be used directly on the production floor must be stable, fail-safe, as well as scalable to different requirements and ideally already provides for redundancy. In the case of VG InLine this is achieved by using the concept of “distributed computing” which allows for the easy scaling of computing power and e.g. in cases where one PC fails another PC will take over its computation task seamlessly.

4. Realization of a 3D-CT inspection in an aluminum-casting production

By putting all these developments into use, 3D-CT today has finally really arrived in production. As often is the case with such novel technologies, the automotive industry has played a pioneering role in introducing this inspection method on a larger scale. A perfect example is the Volkswagen foundry in Hannover that has started to use an at-line 3D-CT scenario to perform random sample tests. In this scenario VW implemented a system where the casting process of several product lines is controlled and surveyed using the capabilities of
3D-CT. Even though this scenario is not an example for and 100% inspection of a product line, it still perfectly illustrates how a serial CT inspection can be implemented successfully. Actual results will be presented.

References