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INTRODUCTION

While computed tomography (CT) scans are common and well-known as a critical evaluation tool in the medical field, they are becoming increasingly important in industrial settings. Three dimensional (3D) industrial CT for non-destructive testing (NDT) has long been confined to the research and development (R&D) environment and its application restricted to structure and defect analysis of high value, complex components and new materials. But imagine an automotive manufacturer being able to fully examine and measure a cylinder head, or an aerospace component manufacturer being able to inspect and measure highly complex turbine blades or parts made by additive manufacturing technologies.

Recent automation, speed, and accuracy developments are driving the migration of CT technology onto the production floor. There, it can be used as a powerful quality control and process optimization tool, providing fast inspection and accurate 3D measurement of components which are difficult to examine by conventional two dimensional (2D) radiography or coordinate measuring machines (CMMs). Because of technological advancements and speed enhancements, the same internal structure visibility provided to medical professionals by CT technology can now be invaluable for manufacturers and inspectors.

UNDERSTANDING CT TECHNOLOGY

CT imaging begins with the acquisition of a large number of 2D X-ray images. The acquisition can be through a fan beam, where discrete slices are radiographed as the component is rotated in small angular steps and moved linearly through the fan beam. As a result, the data collected is a series of slices through the component. Alternatively, it can be done by means of a cone beam, where a cone of radiation captures the target piece and takes discrete 2D images as the component is rotated 360 degrees in small steps. Fan beam CT traditionally provides much better results due to minimized scatter radiation artifacts, but can take up to 100 times longer than cone beam CT. For extremely fast scanning of large parts such as cylinder heads, the sample can be moved in the scanner on the inspection table while x-ray tube and multiline detectors rotate around. This inspection method is particularly useful for parts that are cast molded in a foundry, including automotive and engine parts and cylinder blocks. It also can easily inspect compressor blades and valve bodies. In all cases, the accumulated raw data from inspection is then used in reconstruction algorithms to calculate and visualize the volume data.

The basic data-acquisition hardware components of a CT system are a high power source of radiation, a component manipulation table with rotation unit, and an X -ray detector. The quality of the raw data and the accuracy of all subsequent evaluations are significantly influenced by the sharpness of the X-ray images. The sharpness of the X-ray images ultimately depends on the quality of the source and detector and the stability and precision of the manipulation mechanism.

CT developments are not just in the hardware, but also in the speed of volumetric reconstruction, in the ease of operation, in image quality, and in the storage, retrieval, and management of data.

So how do these advancements apply to the production floor and what do manufacturers need to know?

From shortening the prototype process, to reducing processing costs, to getting faster feedback during the production process, the benefits of CT technology are endless. In order to determine whether CT technology is right for their facility, manufacturers must ask the right questions.

ASKING THE RIGHT QUESTIONS

- **What type of parts am I inspecting?** When dealing with critical machinery in the industrial sector, 2D radiography has its limitations. It is sometimes unable to detect, localize, or visualize the indications and internal geometries found in many of today's complex engineering components. 3D CT can effectively inspect metals, composites, plastics, and additives manufactured or 3D printed parts with complex internal structures.

- **What percentage of parts do I want to inspect?** Previous CT speeds once limited the number of parts that could be inspected to only a few per shift. Advances in scan time, part manipulation, workflow, and software now allow many more scans per hour—approaching full production inspection.

- **How can CT analysis improve my operations?** CT analysis can be useful in assuring product quality, enabling real-time process optimization, and potentially consolidating inspection steps. High quality 3D CT scans and metrology allow manufacturers to compare completed parts to specifications and tolerances with a high degree of accuracy. Automated defect recognition (ADR) software can speed and simplify the pass/fail decision for operators. The increasing speed and production-readiness of CT now allows manufacturers to sample a larger percentage of parts and process the results quickly, which allows for real-time optimization of process parameters, resulting in improved yields, quicker changeovers, and reduced scrap or waste. With 3D data sets available, manufacturers can even consider replacing steps previously analyzed with other technologies into a single operation. Many parts are inspected multiple times with 2D radiography for casting defects and residual materials, in addition to ultrasonic measurement for wall thickness, and sometimes CMM for external measurements. Most of this could be replaced by a single, highly reliable 3D image.

- **What type of CT technology would be best for my manufacturing process?** Over the past 15 years, important hardware advancements, including the development of nanofocus X-ray tubes, have allowed focal spots of less than one micron. This has provided higher resolution and clearer images, e.g. for nano-CT evaluation of electronic components. At the same time, high power X-ray sources can penetrate high absorbing objects, purpose-designed component-manipulation mechanisms, and extremely fast detector systems. There have also coincidentally been advances in volume reconstruction packages and associated software, improving the speed of availability of results and facilitating operations. Furthermore, new advances in ADR and 3D metrology for dimensioning with CT, enable more sophisticated analysis and allow near real-time corrections to the production process. The latest technology advances in scatter correction technology now enable operators to perform fast cone beam CT scans at a high quality level up to hundred times faster than fan beam CT, dramatically increasing CT inspection throughput and precision.

- **How will I adapt CT to my production environment?** No longer just for the lab, more rugged CT systems, improved parts handling workflows, bar-code parts scanning, and robotic manipulators have been integrated into today's production CT systems. This allows them to assimilate more seamlessly to the factory floor environment. In fact, the latest innovation in CT brings the technology directly to the production line. Based on proven technology, it offers a new workflow concept for production process control. It features high speed, automatic helix CT, where a gantry with an X-ray tube and a corresponding 64 channel, multi-line detector rotates around the work piece being transported in the system. The reconstructed CT data of the part under examination is automatically evaluated as the next part is loaded in the system. For example, by scanning a cylinder head in 15 seconds, instead of several hours with conventional fan beam CT, the quantitative production quality data is available almost immediately. This allows for fast adjustment of production parameters if any serious defect is detected or any dimension is out of tolerance. This is of vital importance if the work piece is to undergo subsequent production procedures. In this example, one fast CT scanner can be used to optimize the processes of up to 10 production lines. For critical parts, such as complex turbine blades, fully automated CT solutions now allow 100% inspection with just one operator running three or four CT machines. Operators only have to feed boxes with up to 25 blades in the sample holder and press the "Start CT" button.

- **Where will I find qualified operators?** At one time you needed an advanced degree to operate a CT system. Now Level 3 experts can set up systems with macros and one-button workflows that make it easier for trained production operators to run CT systems and collect the data. Furthermore, the results and reconstructions can be reviewed remotely by experts who can make determinations about the findings. By fully automating the CT scan and evaluation chain, operator time and influence are minimized. Not only saving operator costs, but also greatly increasing the repeatability and reproducibility of the CT results by minimizing the human factor. In addition, new industrial CT operator and data analyst training courses are emerging to help develop the next generation of CT operators.

- **How will I manage the large volumes of data?** A single 3D CT scan can generate 20GB or larger volumes of data. Advanced data processing, storage, and archiving solutions are available to make it possible to manage, share, and evaluate these large data sets. Including data management as a part of the initial project scope is critical to ensuring a successful transition to production CT.

CONCLUSION

By asking the right questions and considering the immediate benefits CT could provide a production facility, manufacturers could drastically enhance industrial inspection processes. Now designed for high productivity and limited downtime, modern industrial components have more intricate features and require advanced inspection techniques. CT provides greater accuracy and speed, increasing productivity and helping production floor operators to meet quality control challenges in a wide range of industrial applications, both in defect detection and in metrology. CT is a continuously evolving technology, and the 3D application for industrial inspections will drastically improve the accuracy of indications, keep machines in operation longer, and ensure the quality control for production process optimization becomes more precise and effective. ■

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