Affordable 3D Computed Tomography for 3D analysis of castings

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Abstract
Typical NDT analysis which involves the detection of porosity, cracks, inclusions and other imperfections in castings, plastics and other mechanical parts by X-ray is standard in non-destructive testing. These features can be imaged far more clearly with microfocus resolution, digital imaging and 3D computed tomography (CT). The new x|argos of phoenix|x-ray combines automated digital 2D inspection with capability for computed tomography in a single system. Due to the fact that the system uses a digital image intensifier for CT, it doesn't require an expensive high contrast flat panel detector. This makes CT affordable even for smaller companies.

Introduction

Microfocus x-ray technology and computed tomography are often applied in failure analysis and quality assurance in many areas of the automotive industry. These techniques can be used to inspect welds, compound materials, mechanics, and castings. The detection of voids, inclusions, and cracks in platings, plastics, and other mechanical parts is standard in non-destructive testing by X-ray but achieves a higher level of detail with microfocus tubes and digital imaging. Expanding upon this technology into computed tomography allows spatial relationships and quantitative defect analysis to be performed upon a sample. By allowing virtual slicing and sectional views in any direction of the 3D-volume, this technique will substitute destructive mechanical slicing and cutting in many applications.

Figure 1: The x|argos, the new 2D/CT Multi-tool from phoenix|x-ray

Strong competition in the automotive supplier market has caused x-ray inspection to become a standard method of quality control high volumes, film X-ray has become slow and impractical. A digital method of inspection is therefore necessary. Also, with some materials, it is the smaller features which may be of greatest concern. Cracks of only a few microns in diameter require microfocus X-ray in order to be seen. This has been a concern of quality control for some time, but more so in a highly contested market. Many flaws can easily pass by an X-ray tube with a larger focal spot.

As automotive technology has progressed, complexity of structures and products has also reached new heights. For many quality control experts, a 2D image simply is not detailed enough. For example, a 2D image of a metal foam will give an overall impression of the density of the object, but the pore density and wall thickness is indeterminate. Using computed tomography, however, these measurements can be found quantitatively. CT allows the user to manipulate a binary volume representation of the sample, enabling them to measure objects in 3 dimensions. Pore density analysis then becomes a simple matter of selecting pixels.

Until recently, however, most CT options were priced well outside the budget of most small to medium sized businesses. High quality CT required an expensive flat panel detector in order to reduce artefacts. A recent development at phoenix x-ray, however, now enables use of the image intensifier for CT. This is primarily a software development, using a thorough understanding of how artefacts are created and can be mitigated. Now even large castings can be scanned affordably. One such tool is the x|argos from phoenix x-ray. This device allows even larger castings to be scanned using a directional microfocus tube and an image intensifier.

Theory

Imaging with microfocus X-ray tubes

The theory behind generating X-rays is relatively well known. A tungsten filament is heated (heating current/filament current UH) in an evacuated tube, releasing electrons. Due to the potential difference between filament (cathode) and anode, the electrons are accelerated from cathode to anode, where they strike at one third the speed of light. The filament current is controlled by means of the Wehnelt grid, which is held at a negative potential (voltage UG). The beam is then deflected and focused into a narrow beam that then strikes a target. The direct beam target of a directional X-ray tube, because of its cylindrical and massive shape, can be used for voltages 10-20 times as high as those used for transmission tubes. This enables very dense and larger samples, such as castings to be imaged.

The difficulty in using the x|argos for CT has been the image intensifier. This is a device which introduces some artefacts due to design. Unlike a flat-panel detector, which converts X-rays into visible light which is then directly converted into information using photo-diodes, an Image Intensifier converts and focuses the energy so that it can be captured via a CCD camera. Attempts to create a CT using an image intensifier resulted in artifacts due to the nature of the lenses. The new software development takes into account these geometric differences and corrects them, creating a true voxel volume representative of the sample.

Limitations of 2D X-ray imaging

The image produced with a conventional X-ray imaging system can range anywhere from a 1:1 magnification ratio to well over 1000 times magnification with an advanced technology microfocus x-ray source. Very fine feature recognition is achieved at these very high magnification levels, but there is an inherent limitation. While measurement accuracy can be very high in the vertical and horizontal planes of the image, which represent the height and width of the sample, the depth of the sample is only measurable in terms of grey scale intensity or density values. In other words, it is possible to image a defect in a sample such as a void in a casting or a crack in a weld and measure the height and width accurately, but there is no effective way to measure the depth of such a defect with a conventional two-dimensional image.

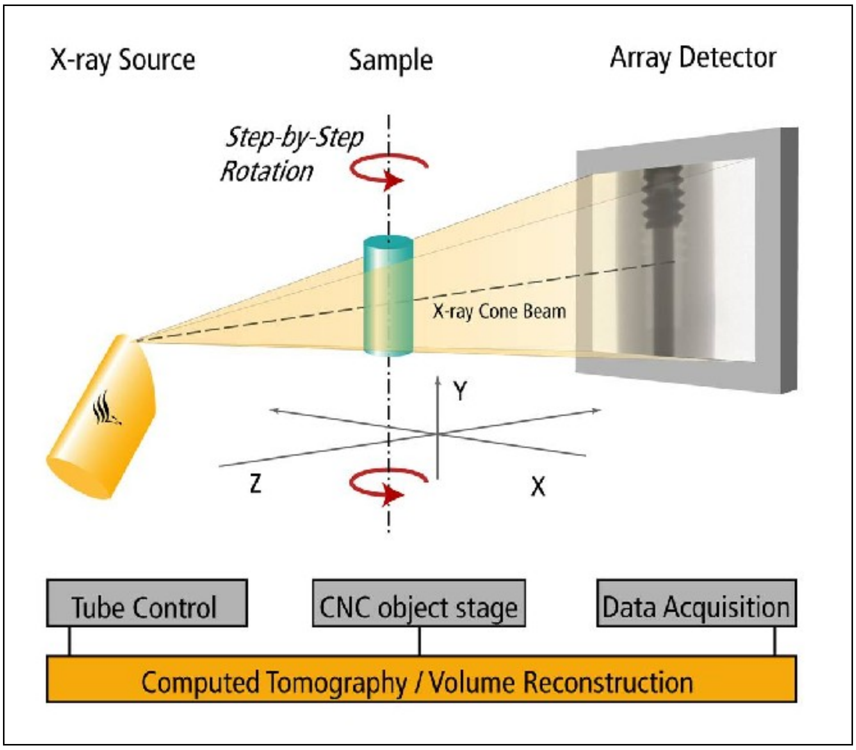

Figure 2: Geometry of machine and description of CT.

In some instances, a sample could be salvaged if the defect can be accurately located within the depth of the sample for removal or repair. In other situations, changes can be made to the manufacturing process that will correct the problem for the production line. Achieving depth recognition, in situ with height and width recognition is only made possible by three-dimensional imaging. In fact, there is an ever increasing number of situations where three-dimensional sample information is a prerequisite to making an accurate determination about the status of a sample or an indication within. For example, in the case of an electrical assembly where a wire crimp is failing or in a complex fuel injector nozzle where a mechanical failure is occurring, three-dimensional information can identify the problem area to be corrected, which is not otherwise detectable when imaging the sample in a conventional two dimensional x-ray process, which images the sample through its entire depth.

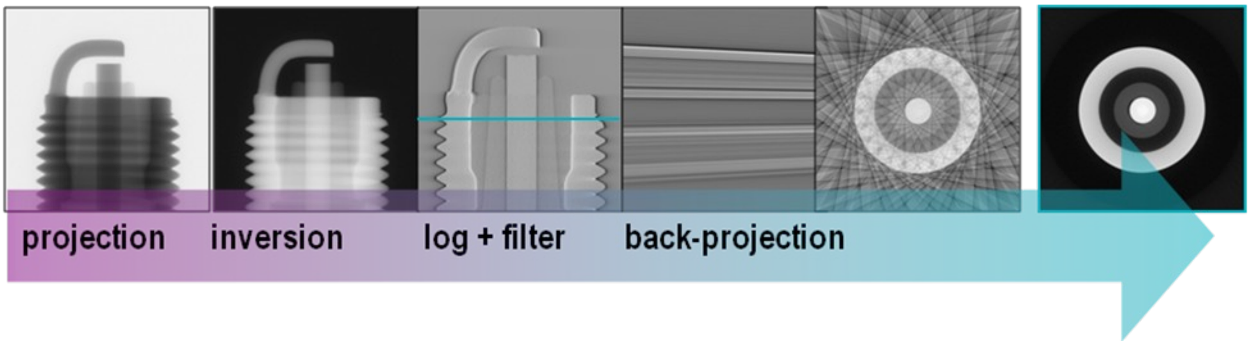

Figure 3: Description of CT. The image stack is inverted and reconstructed using the geometry of the machine.

For these challenging x-ray inspection applications, the most remarkable results are obtainable by using computed tomography with a microfocus X-ray source: microfocus-CT. Microfocus-CT, which uses a highly stable and reliable microfocus X-ray tube as the X-ray source, is one of the most sensitive CT solutions producing ultra-high resolution results. The microfocus X-ray source enables detectability of features with sizes down to the range of a few microns, which are otherwise not easily detected with most other non-destructive x-ray methods.

Microfocus-CT with volumetric capabilities provides the ability to non-destructively visualize samples in three dimensions, facilitating the reverse engineering process. In doing so, productivity can be improved by reducing development costs, improving safety factors and increasing yields. Additionally, non-destructive slicing and sectional viewing of samples are valuable features incorporated into microfocus-CT to facilitate this process as well.

Principles of Microfocus-CT

Generating three-dimensional images using microfocus-CT starts with the acquisition of a series of two dimensional X-ray images. The series of two dimensional X-ray projections is a collection of images acquired while progressively rotating the sample step by step through a full 360° within the field of view at increments of less than 1° per step. These projections contain information on the position and density of absorbing object features within the sample. This accumulation of data is then used for the numerical reconstruction of the volumetric data. This volume data is compiled as a visualization of the reconstructed layers in a three-dimensional view.-

In order to reproduce an accurate reconstruction of the volumetric data, there are two conditions that must be met. First, the entire sample depth/diameter throughout the entire 360° rotation must remain within the field of view and cone of radiation so that the full sample diameter is completely displayed in each projection captured in the acquisition process. Second, the entire geometry of the sample, meaning every acquisition angle throughout the full 360° rotation, must be fully penetrated and imaged at the energy level with which the sample is scanned. This can be accomplished successfully even for higher density samples by a powerful X-ray source and properly preparing i.e. “hardening” the x-ray beam by filtering out long wavelength X-rays.

System description

The x|argos system for high resolution 2D X-ray inspection and CT

With its 6 axis CNC manipulation including a C-arm for tube and detector and its high power directional tube, the x|argos provides accuracy and microfocus resolution for the inspection of samples up to 100 kg. Fully automatic inspection programs allow for large-scale samples to be tested in a production environment. Additional modules may be created using Xe^2, the X-ray Evaluation Environment of phoenix|x-ray. This program allows the user to create modules based on edge detections, greyscale measurements, void percentages, creating a truly customizable tool.

Figure 4: The directional microfocus tube examining a large casting. The directional cone allows for higher energy X-rays to be generated.

In addition to standard 2D inspection tasks, microfocus CT enables quantitative defect analysis as well as detailed three-dimensional measurements. By replacing destructive inspection and measurement methods, CT saves costs and time per sample inspected. Also, with a binary volume, one is not limited to sectioning in only one direction. It is possible to slice through literally any direction, using graphical software. The new x|argos represents a multitool with 2D inspection capability as well as all benefits of computed tomography. This unique combination provides an excellent cost-benefit ratio and opens a new dimension of quality control. The size of the manipulator allows for the widest possible sample range- anywhere from very small samples with very high resolution to castings 3 feet tall.

As the x|argos contains an open tube, maintenance requires only the occasional changing of the filament and turning of the target. From time to time it may be necessary to clean the cables going from the generator to the tube. An automatic check that comes standard with all open tubes checks the condition of the filament and the target every time the machine turns on. From the user standpoint, nothing else is required.

Results:

Results from the x|argos have been promising. The casting shown in Fig. 5, 6, 7 and 8 was examined using an image intensifier. The resultant volume has some artefacts remaining, but the pore density can be clearly and quantitatively measured. As this is a binary volume, we can slice through the part in any direction, giving the spatial measurements of each of the pores. The higher density material can also be removed, if only the spatial relationships of the pores are of interest.

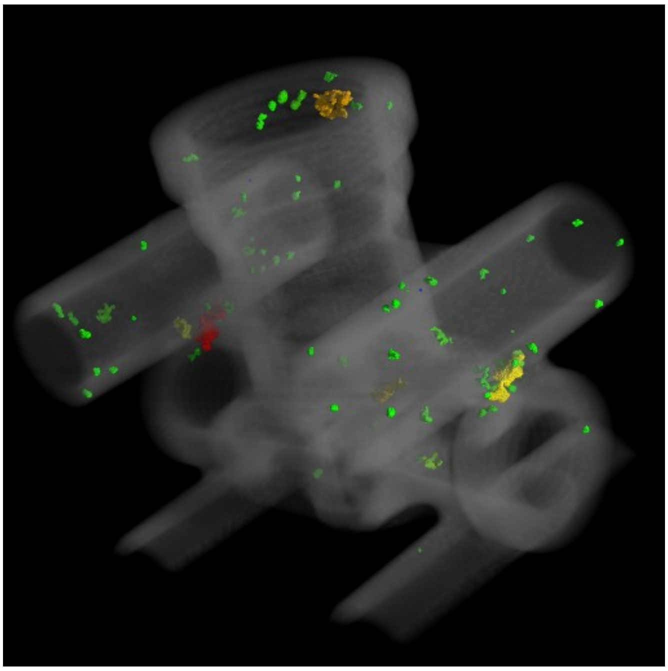

Figure 5: Example of Pore Analysis using x|argos with image intensifier. Smaller Pores colored green, larger porosities yellow, orange and red.

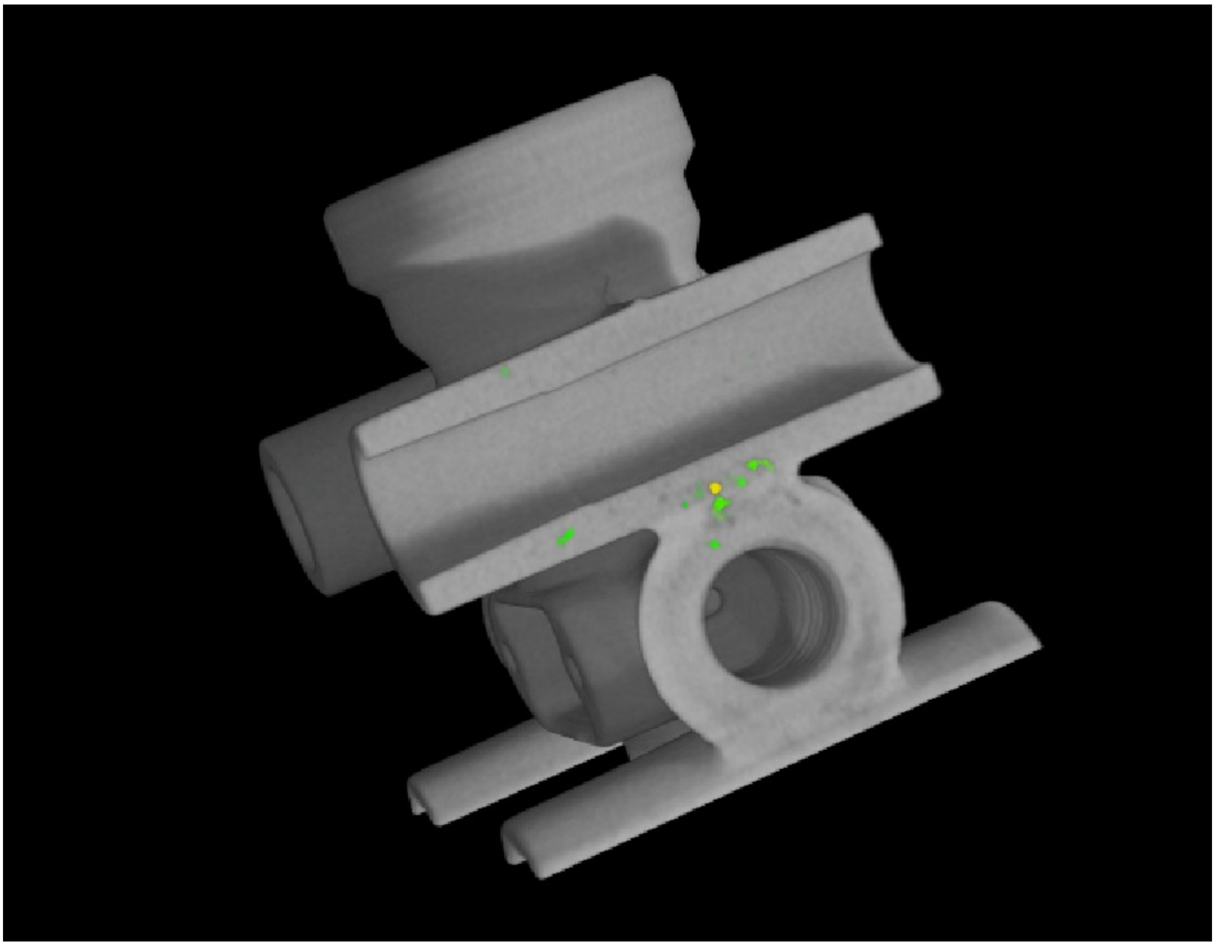

Figure 6: A 3D sliced view of a metal casting. Some of the larger voids are highlighted in green and yellow.

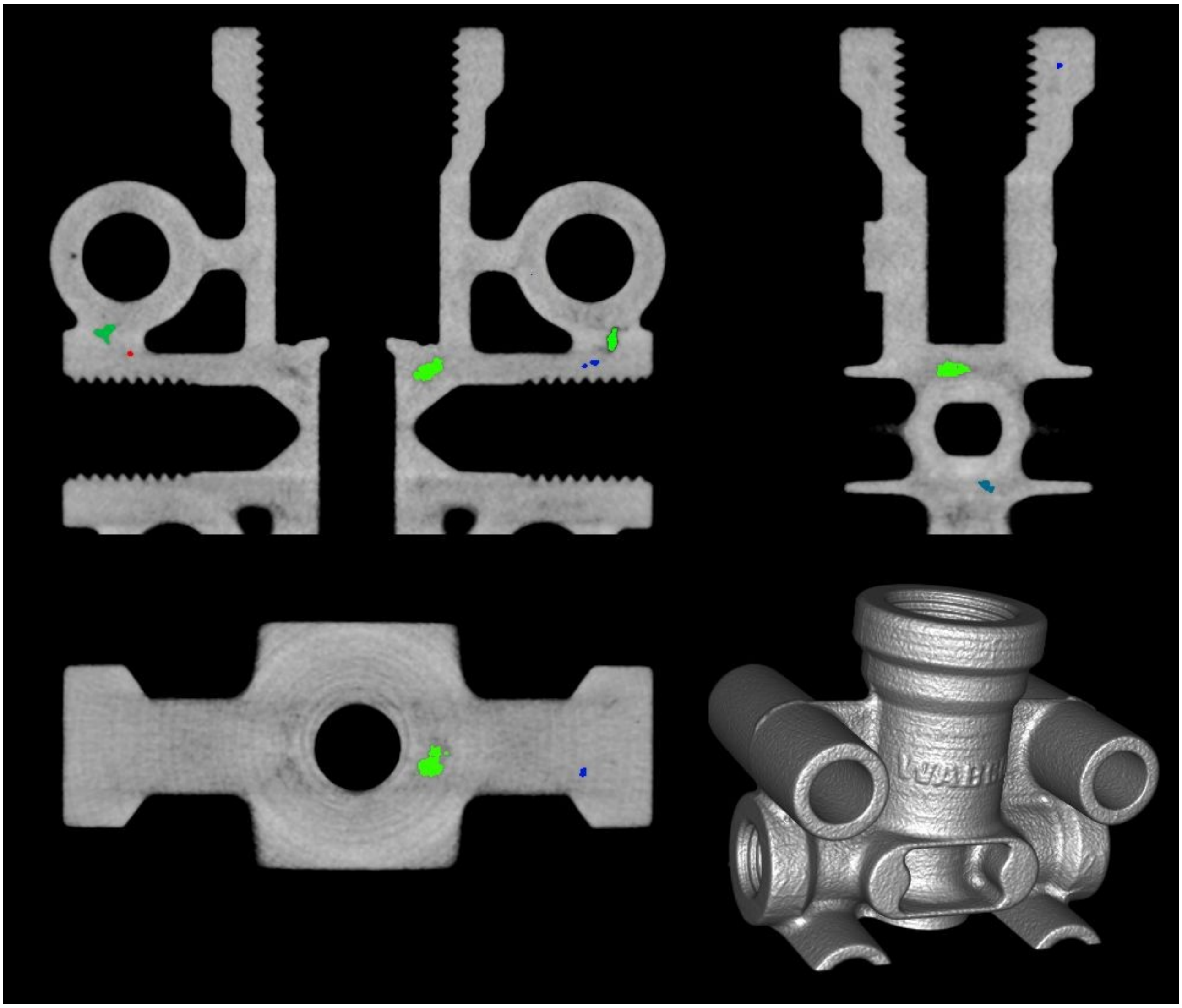

Figure 7: Four views of casting, examing in the xy, xz, and yz planes, as well as in 3D. Pores are highlighted using pseudocoloring.

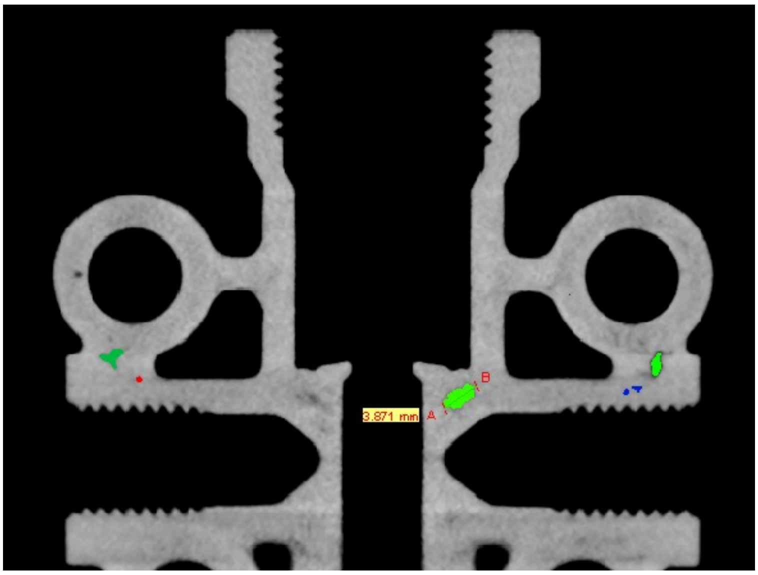

Figure 8 Axial slice of casting showing pore density and measurement of pore.