AFFORDABLE 2D INSPECTION AND 3D COMPUTED TOMO-GRAPHY FOR 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 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 chain for CT, it does not require an expensive high contrast flat panel detector. This makes the advantages of CT affordable even for lower budgets.

Keywords: Microfocus X-ray inspection, Computed Tomography (CT), Defect Analysis,

1.   INTRODUCTION

2D X-ray inspection 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 castings 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 evaluations 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.

Strong competition in the automotive supplier market has caused X-ray inspection to become a standard method of quality control in the casting industry. With such high volumes, conventional film X-ray has become slow and impractical. A digital method of inspection was 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. Many flaws can easily pass by an X-ray tube with a larger focal spot.

Figure 1. With its 240 kV high power tube, the x|argos provides microfocus resolution for 2D real-time-inspection of samples up to 100 kg as well as affordable 3D Computed Tomography

As automotive technology has progressed, complexity of structures and products has also reached new heights while the wall thickness of castings has continuously decreased. 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 budgets. Conventional CT required an expensive flat panel detector in order to reduce artefacts. A recent development at phoenix|x-ray, however, now enables use of digital image chains (image intensifier + 2 or 4 MPixel CCD camera) for CT. One such tool for scanning castings affordably is the x|argos from phoenix|x-ray. This device allows even larger castings to be scanned using a directional microfocus tube and a digital image chain.

2. THEORY

2.1 Imaging with microfocus X-ray tubes

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

2.2 Limitations of 2D X-ray imaging

The image produced with a X-ray imaging system can range anywhere from a 1:1 magnification ratio to well over 25.000 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.

In some instances, a sample could be salvaged if the defect can be accurately three-dimensional located within 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. Computed Tomography shows the exact location of the defect in the sample providing information on size, volume and density of inclusions and cavities. Due to the fact that CT images are rich in contrast, even small defects become detectable.

For many X-ray inspection applications of castings, 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 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.

3. 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.
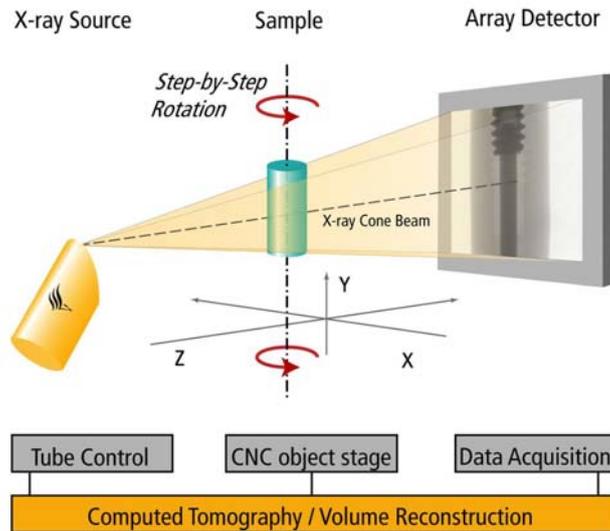
Figure 2. Geometry of machine and description of microfocus CT.

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 the proper use of filters to reduce long wavelength X-rays.
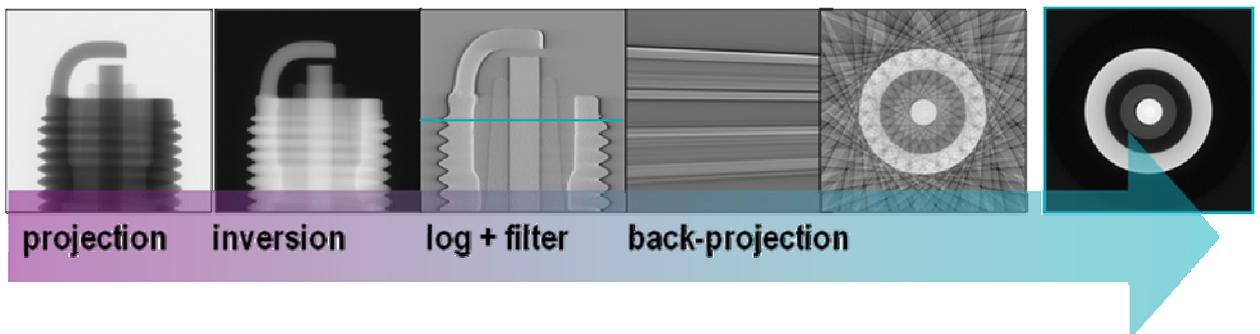

Figure 3. Description of CT. The image stack is inverted and reconstructed using the geometry of the CT-system.

The difficulty in using common 2D X-ray inspection systems for CT has been the image intensifier. This is a device which distorts the X-ray image due to its 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 a digital image chain resulted in artefacts due to the distorting nature of the lenses. The new software development takes into account these geometric differences and compensates them, creating a true voxel volume representative of the sample.

4. SYSTEM DESCRIPTION

4.1   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 240 kV high power directional tube, the x|argos provides accuracy and microfocus resolution for the inspection of samples up to 100 kg. 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.

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. A directional microfocus tube examining a large casting. The cooled reflection target 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.

As the x|argos contains a longlife open tube, maintenance requires only the occasional changing of the filament and turning of the target. An automatic check that comes standard with all phoenix|x-ray 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.

5. RESULTS

Results from the x|argos have been promising. The casting shown in Fig. 5, 6, 7 and 8 was examined using a digital image chain. 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.

The new x|argos represents a multi-tool 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.
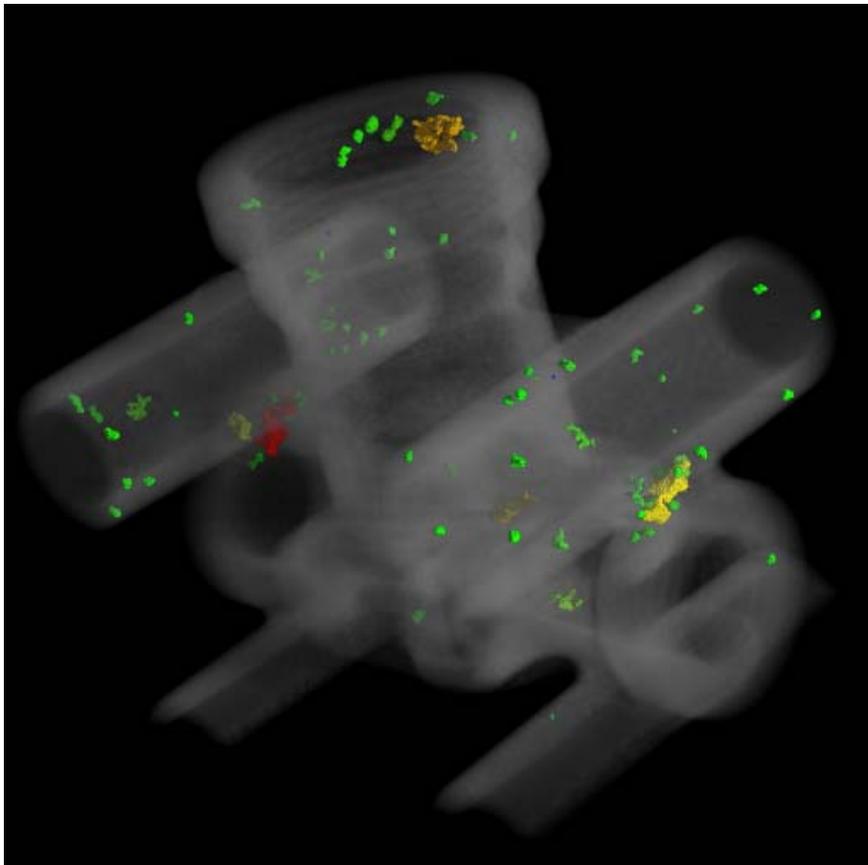

Figure 5. Example of pore analysis using x|argos with digital image chain. Smaller Pores colored green, larger porosities yellow, orange and red.
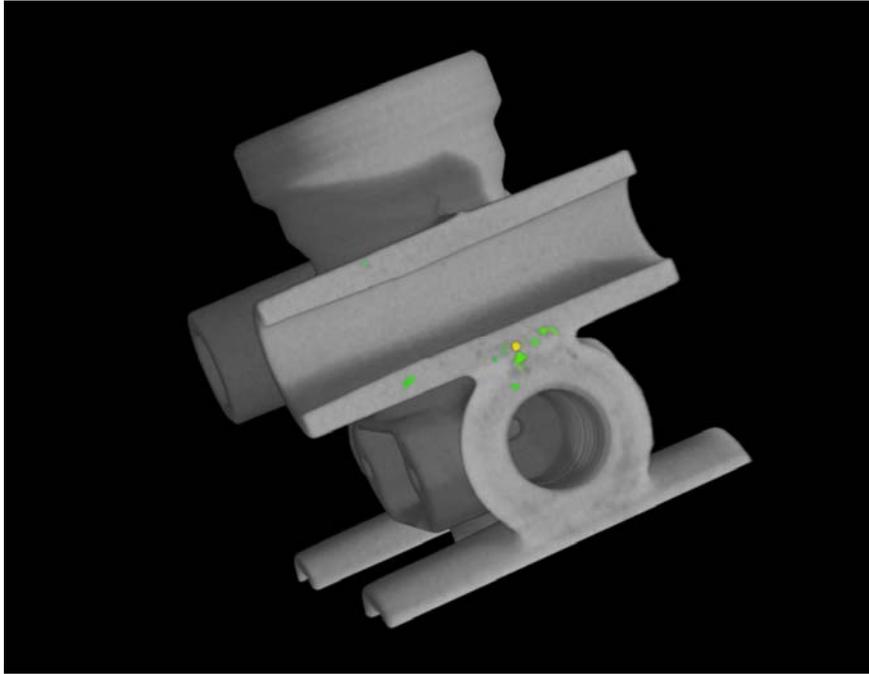
Figure 6. A 3D sliced view of a metal casting. Some of the larger voids are highlighted in green and yellow.
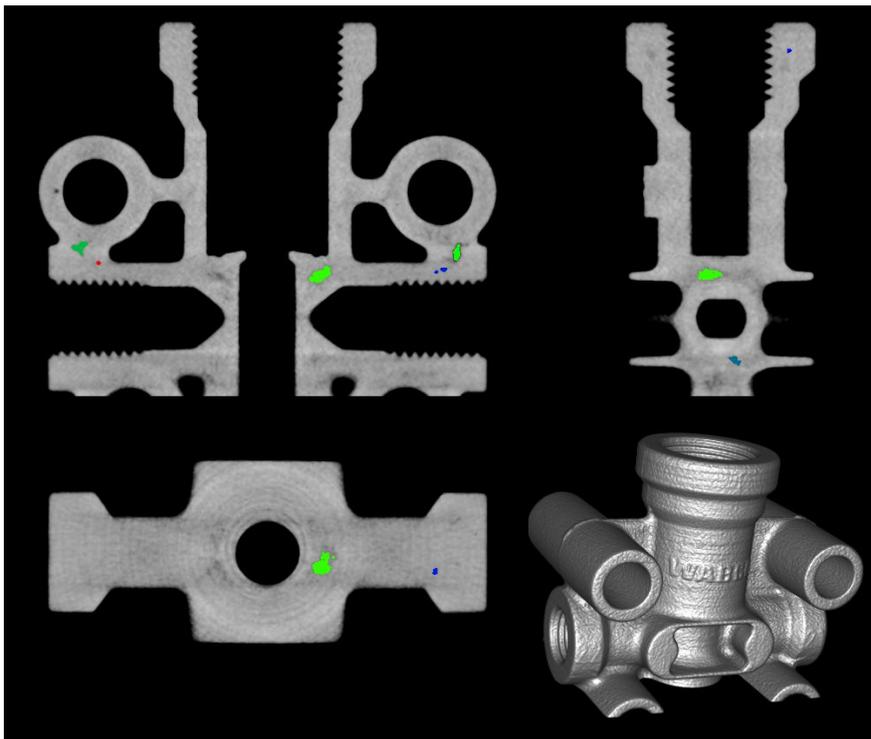

Figure 7. Four views of casting, examing in the xy, xz, and yz planes, as well as in 3D. Pores are highlighted using pseudocoloring.
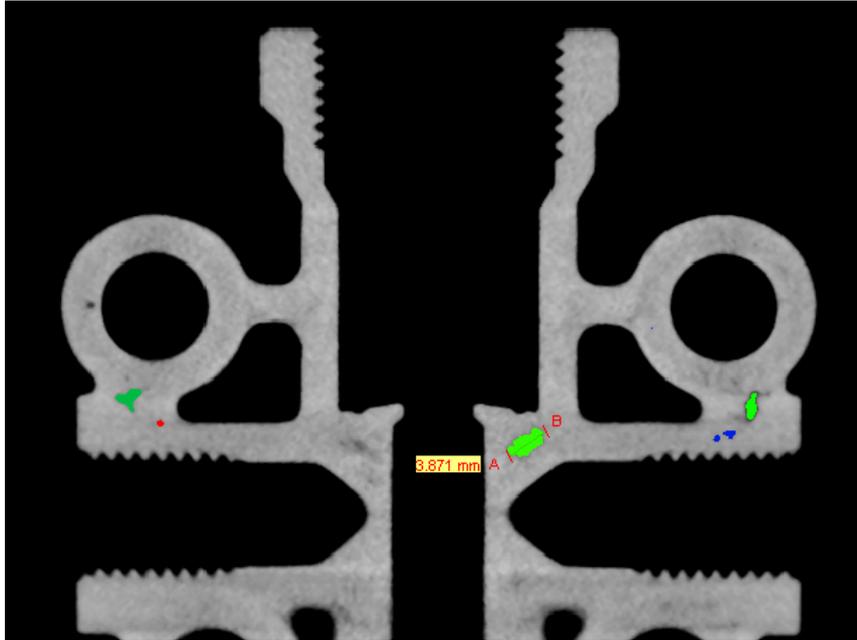
Figure 8. Axial slice of casting showing pore density and measurement of pore.

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