Accelerator Based Large Format Computed Tomography

CINDE
CANADIAN INSTITUTE FOR NON-DESTRUCTIVE EVALUATION

NDT in Canada
NDTiC 2018
Canada's NDT Conference
June 19 - 21
Halifax Convention Centre
Halifax, Nova Scotia

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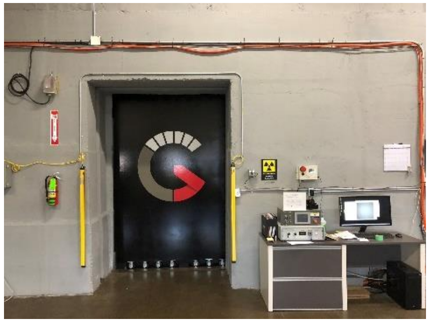
WHO IS JESSE GARANT METROLOGY CENTER

JESSE GARANT
METROLOGY CENTER

Jesse Garant Metrology Center provides solutions that helps create meaningful advancements in industry. By focusing on advanced imaging solutions such as Industrial Computed Tomography with the support of production x-ray and 3d scanning services, we deliver critical insights into inspection projects that are difficult to measure. With over 15,000 unique parts CT scanned, spanning eight years in over ten different industries, we continue to invest in our Industrial CT Scanning Services and have the proper infrastructure in place to operate efficiently.

WHY USE COMPUTED TOMOGRAPHY



1. Cabinet/Vault

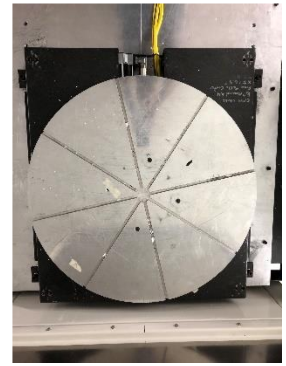
A shielded enclosure that houses all the components of an xray/CT which also prevents minimum leakage of radiation to the surrounding area.

Can vary in size and weight depending on the amount of radiation produced by the source

2. X-Ray Source

X-ray sources come in a variety of energy settings with different spot sizes. The key points for an x-ray source are:

Source power and voltage
Spot size
Consistent power setting



3. Precision Rotary Table Positioner

The rotary table is required to capture the projects over a 360 degree arc.

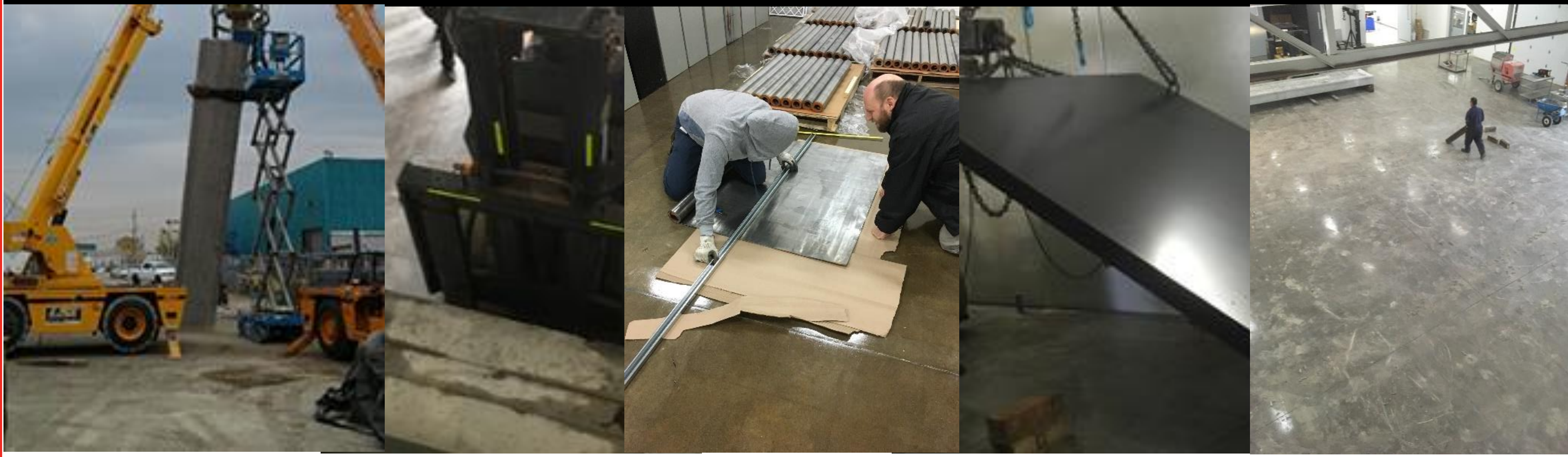
This distance needs to be known with high precision in order to get accurate dimensions

4. Detectors

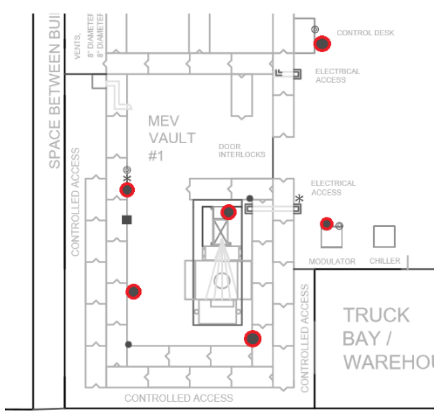
A digital detector is a device that captures x-rays, converts them to light and then recorded. The inverse of what computer monitors do.

Digital detectors come in a variety of pixel pitch's which mean the space between pixels.

VAULT CONSTRUCTION PHASE



- The base vault construction took just over 4 months to assemble and complete.
- Walls are over 6’ (1828.8mm) thick
- The weight of the vault topped out at 1.8 million lbs.
- The door alone weighs 14000 lbs and requires a 3HP motor to move it.



VARIAN M3A LINAC

- Modulator Cabinet
  - Converts and monitors the main electrical power to high voltage pulses to the magnetron
- Magnetron
  - Provides high frequency microwave power used to accelerate the electrons in the waveguide.
- Waveguide
  - Tube that guides the electromagnetic waves from the magnetron to the accelerating guide where the electrons become accelerated.
- Target
  - Usually made from tungsten for industrial purposes is located at the end of the accelerating electrode, used to convert the electrons to Xrays
- Chiller/Water Cooling System
  - Required for the operation of the system and allows the components to operate constant temperature

DIGITAL DETECTORS

Linear Detector Arrays (LDAs)

LDAs are one-dimensional x-ray detectors that consist of a single row of x-ray sensitive detectors. In order to obtain a two-dimensional image from such a detector it is necessary to move the detector, or the object in a direction perpendicular to the length of the array. In order to maintain regular image geometry (square pixels), the speed of movement has to be carefully synchronized with the line exposure time of the array. The width of two-dimensional images acquired by an LDA are limited by the number of pixels comprising the width of the array, however, the length is unlimited. LDAs are also suited to perform 2D CT which obtain single CT slices through an object. Although slower, 2D CT is preferable to 3D CT (using an area detector) for applications where scattered x-rays are a problem; for example for high energy applications, radioactive components or when examining dense materials.

Digital Detector Arrays (DDAs)

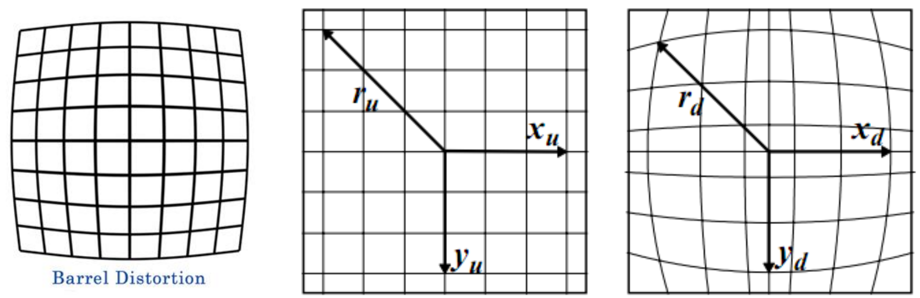
DDA’s are composed of two principle imaging components. The first imaging element is a scintillator screen that converts the x-rays into visible light. A wide range of scintillation screens and materials are suitable and most manufacturers offer different screen options. This screen is coupled to an array of photosensitive photodiodes which convert the visible light to an electrical charge. This charge can be read out via an array of switches of Thin Film Transistors (TFT’s) and digitized. The digitized values for each photodiode, can be used to generate a corresponding grey level value in single image pixel. Thus the array of photodiodes allow a digital radiograph to be captured, each diode corresponding to a pixel in the radiographic image. However currently there is manufacturing limitations in regards to size. The largest most common panels are approximately 16” in size.

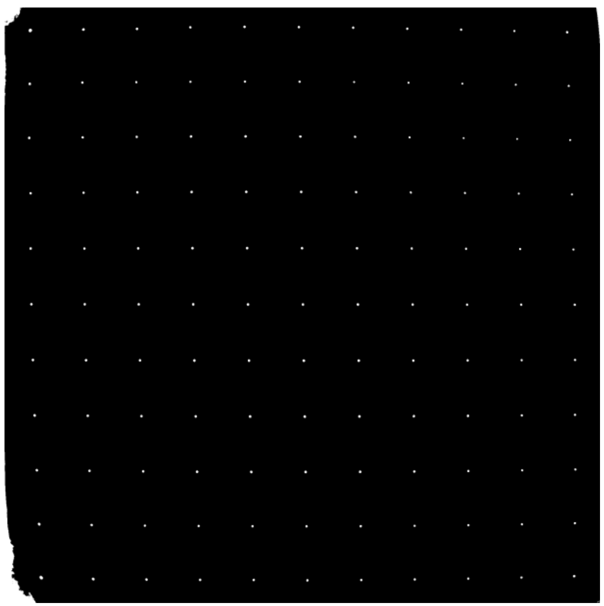
CUSTOM BUILT PANEL

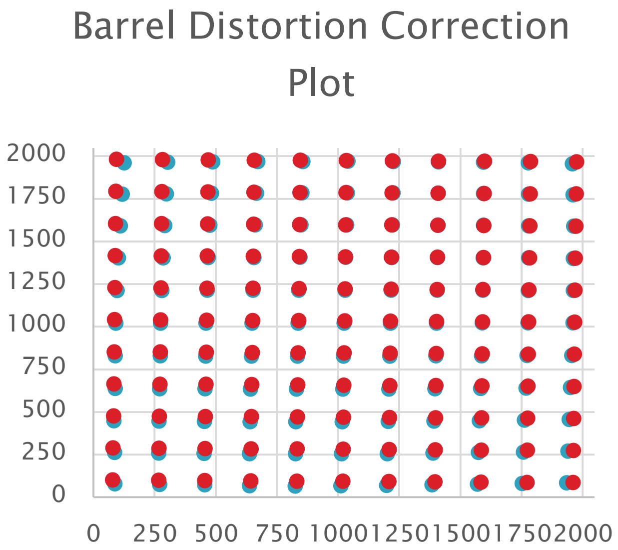
- The panel is a custom built 1 meter by 1 meter panel.
- Has an effective resolution capable of doing 2048x2048 @ 16bit (500um).
- Capable of withstanding energies up to 6MeV or 8 Gy/min
- Mountable to either an actuator or simply on feet.
- Fast integration time of 10ms

CUSTOM BUILT PANEL

- Due to the size and the construction of the detector it is subject to Negative Optical Distortion (barrel distortion).
- The barrel distortion caused from the distance from the point source to the detector from an un flattened beam needed to be corrected.
- We took a precision hole patter which we first binarized and used a special algorithm to correct for the optical distortion.





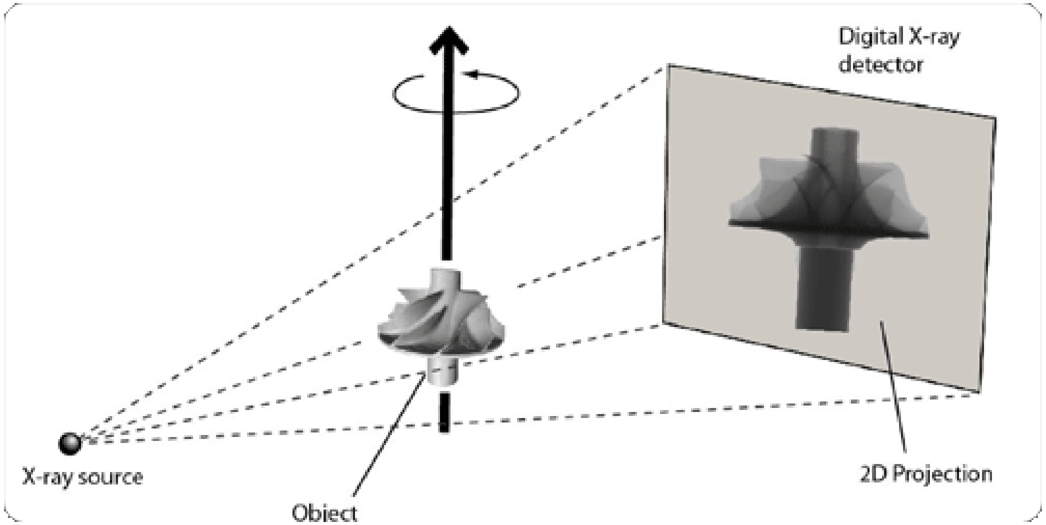


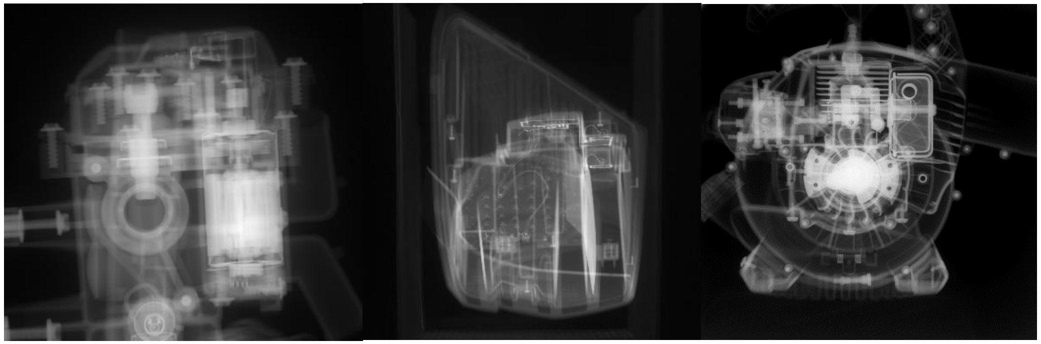
HOW DOES IT ALL WORK TOGETHER?

The process of computed tomography is that it takes several thousands 2D x-ray images called projections covering a total of 360 degrees.

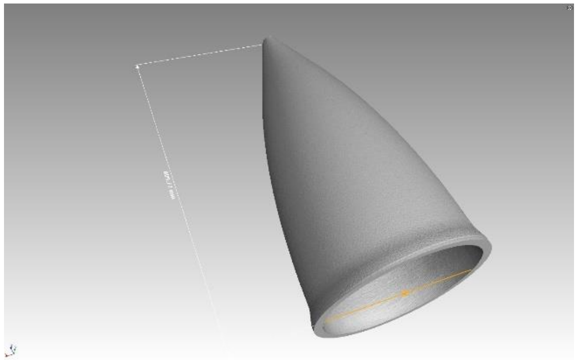
The object is fixtured in a low density material to prevent movement during the 360 degree rotation.

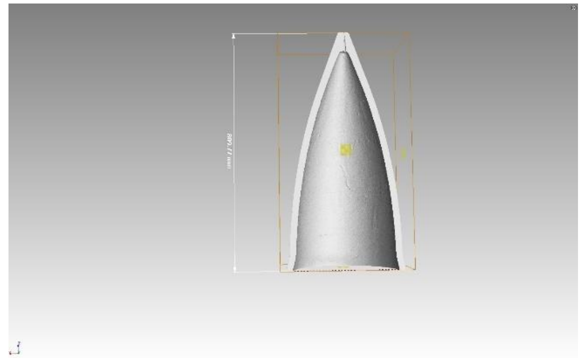
These projections are required for the reconstructor to create a 3d dimensional dataset (VOXEL).

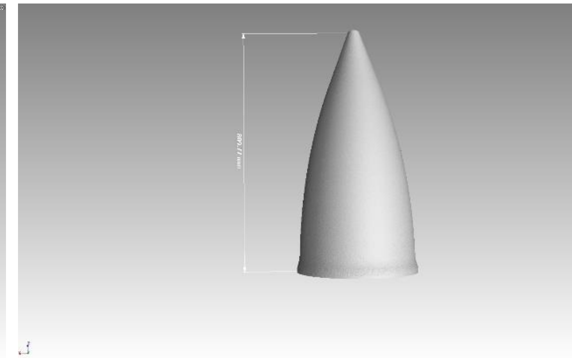


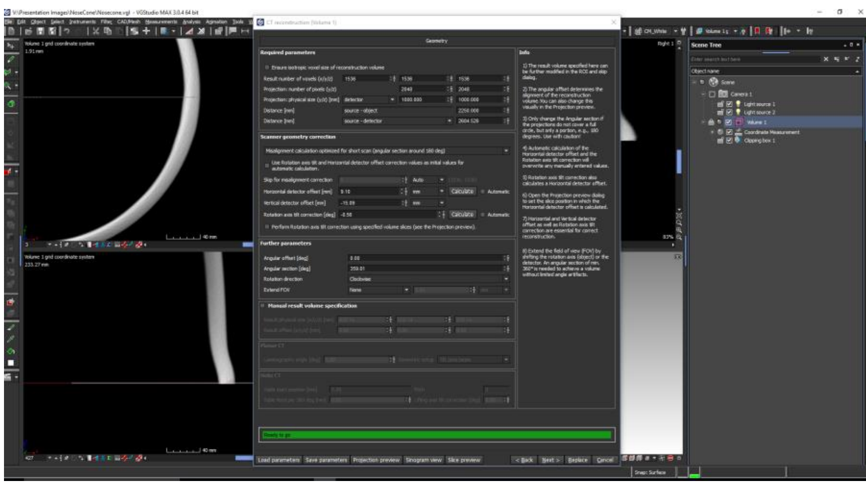


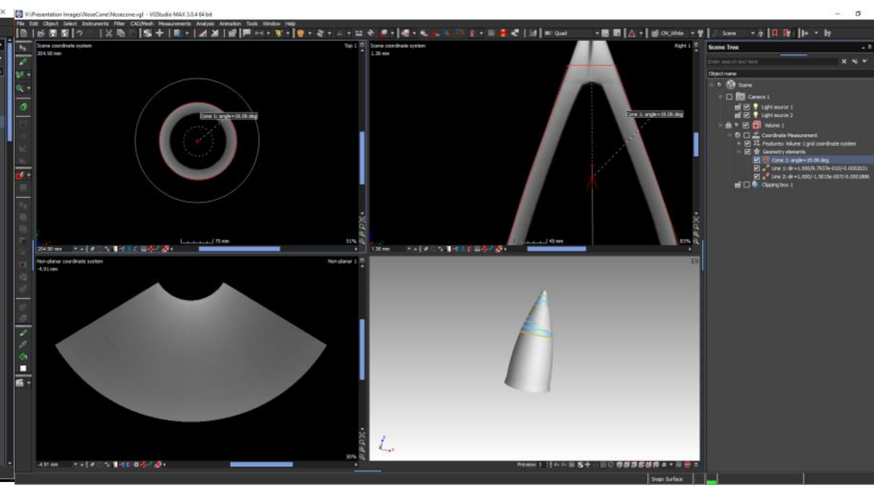
USING VOLUME GRAPHICS TO RECONSTRUCT ALL DATA







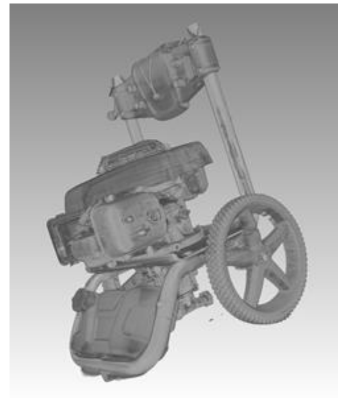


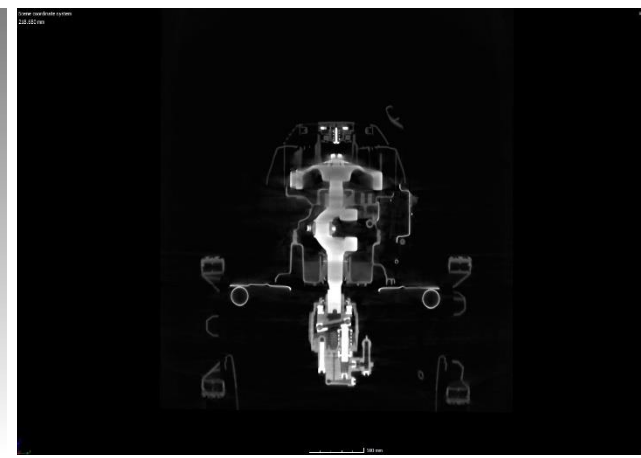


LINAC TESTING

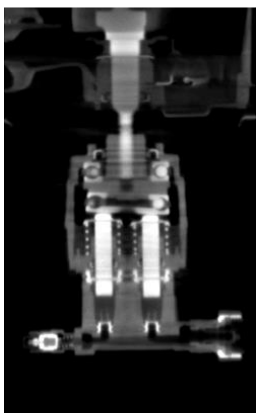
LINAC TESTING PHASE

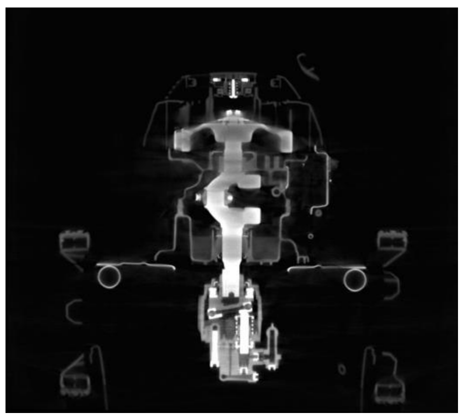
- With the reconstruction tools in VG this allowed us to apply different scanning techniques (Field of View Enlargement, HELIX, etc)
- Our scans using the large format panel yielded little to no scatter from materials of different densities.
- Connections and welds can be seen quite clearly between dissimilar materials and as accurate as 500 microns

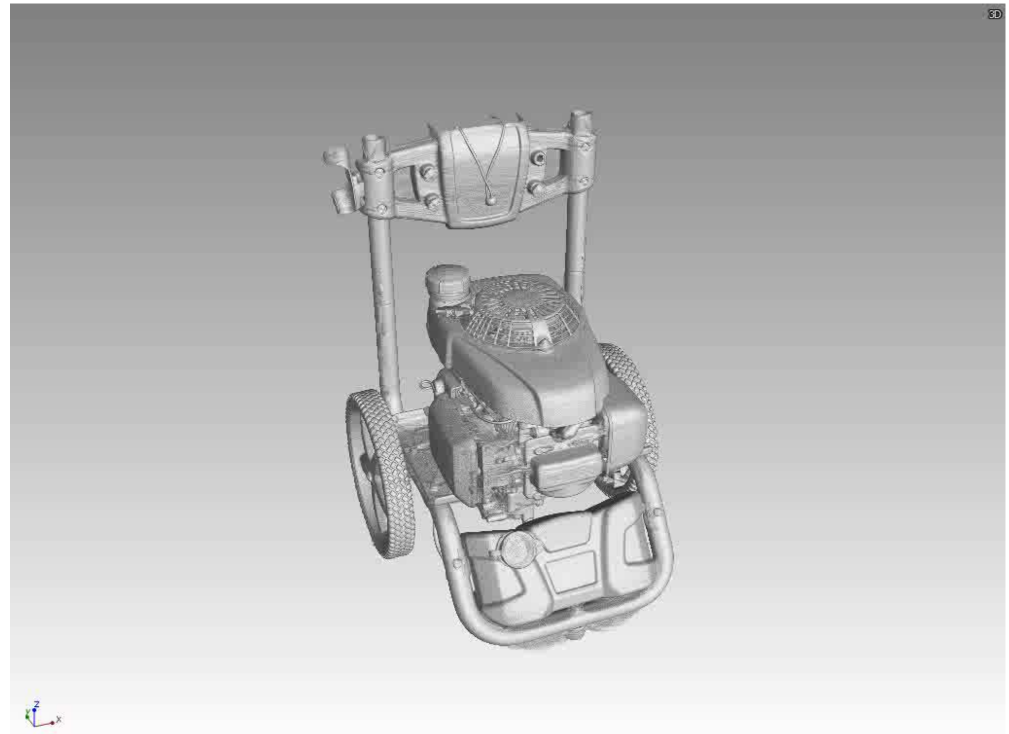


TESTING PHASE

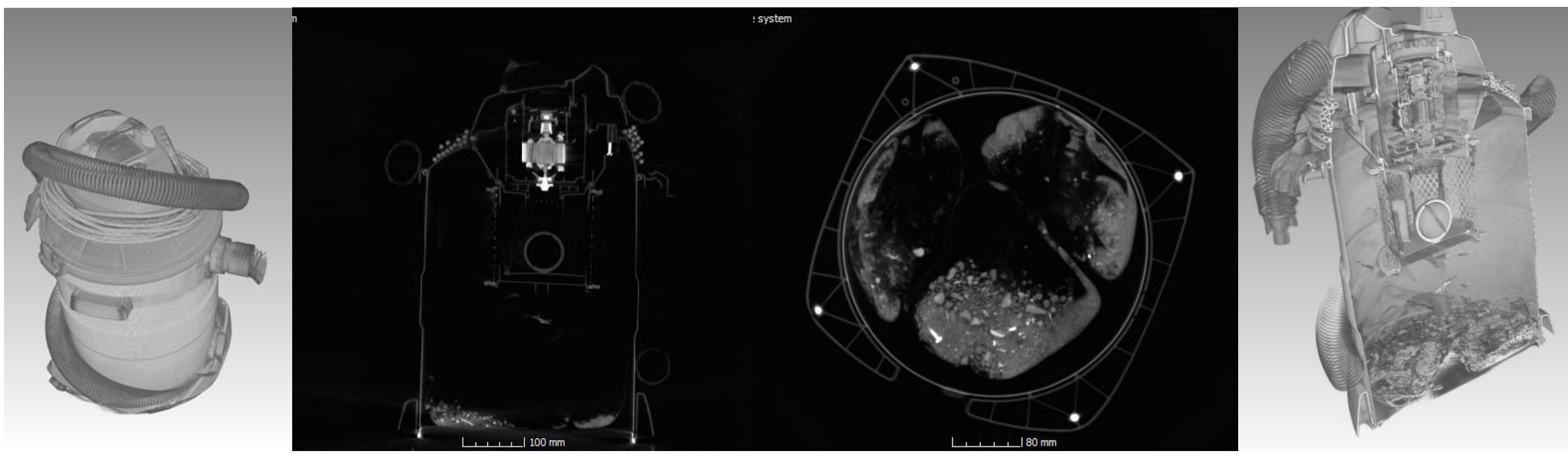






TESTING PHASE

Ever wonder how full your ShopVac is without opening it?

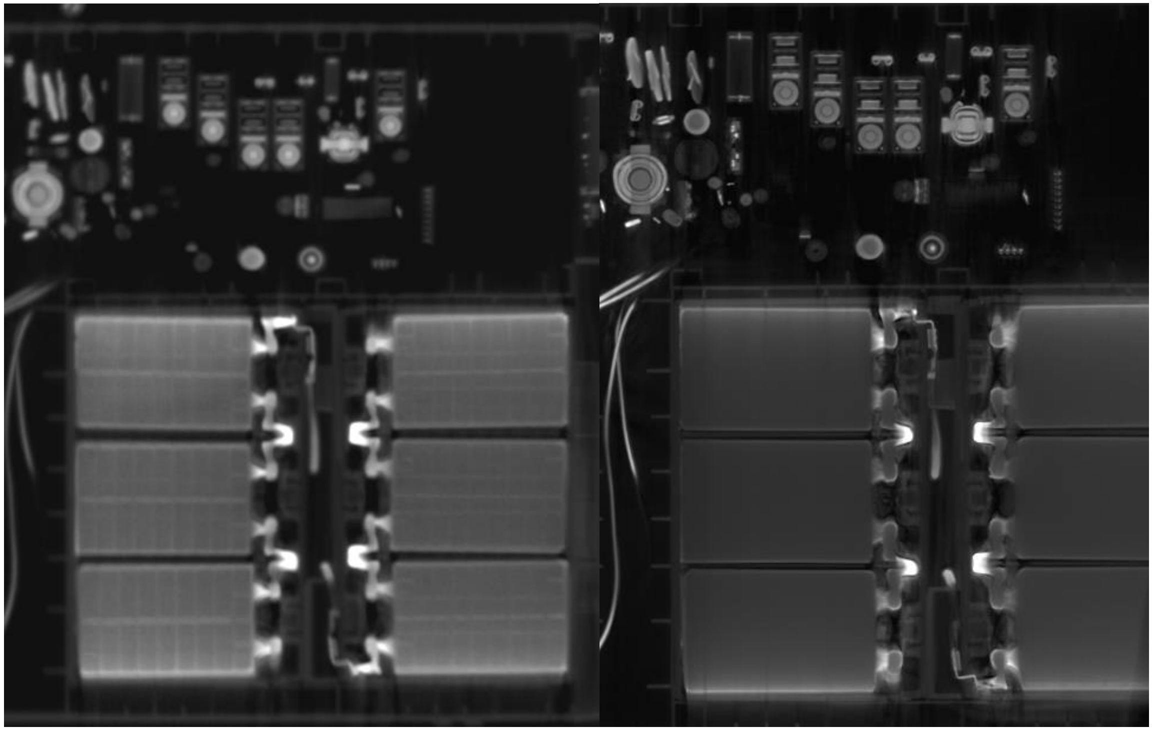


SO WHY USE A LINAC?

Benefits of using a Linear

Accelerator for CT:

- The ability to see clean interfaces between low density and high density material.
- The grayscale of the low energy scan; the material doesn't correspond to the real material as shown in the MeV scan data.



A UPS Power Supply Scanned on 3MeV (Left) & 450KeV (Right)

SO WHY USE A LINAC?

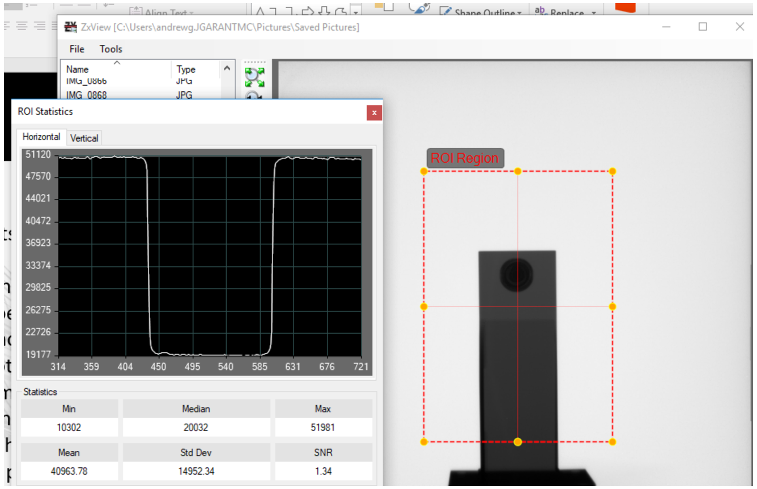
Benefits of using a Linear

Accelerator for CT:

- High energy radiation is less likely to be scattered due to the energy removed by the scattering of the photon. In short basically means its more likely to continue to travel in the direction intended.

- As the energy of photons increase the probability of interaction drops.

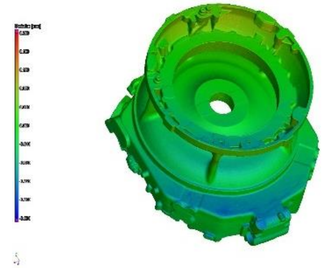
- The imaging quality great increases due to the high signal homogeneity and lower beam hardening artifacts.

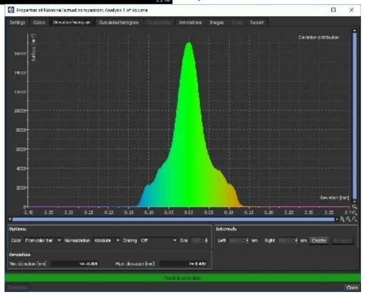


A small (4x 1x 12) Additively Manufactured steel bracket is used to compare the statistics between the 450KeV and the 3MeV

SO WHY USE A LINAC WITH DDA? TIME!

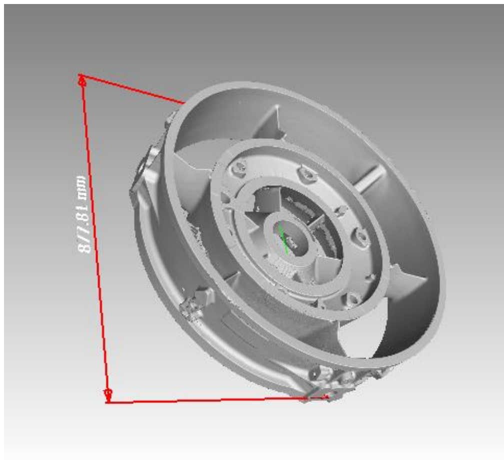
- Going to a large format flat panel has drastically improved the acquisition time at little to no reduction in image quality for most parts.
- If using a 2048 pixel horizontal line, Nyquist states that we should be using 3201 frames for proper acquisition.
- Typical LDA run time at 3201 projections per slice @ 90 seconds per slice at .5mm increments for a total of 915 slices for the casting. This in turn equates to **22 hours!**
- With the large format DDA panel we are down to 27 minutes for 3201 frames for the same 2K matrix.
- There is little to no discernable loss of quality and no more missed defects on the Z axis

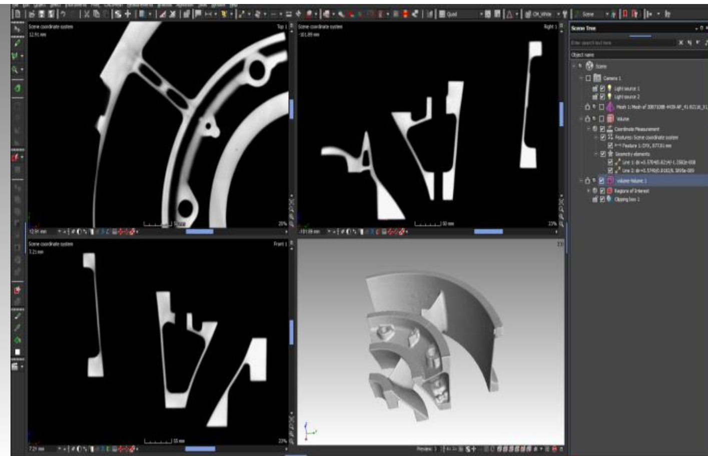


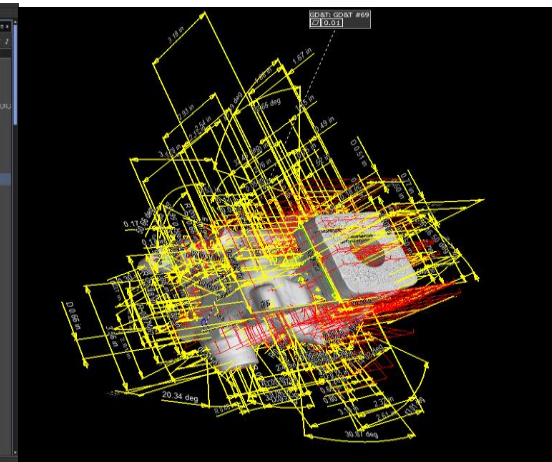


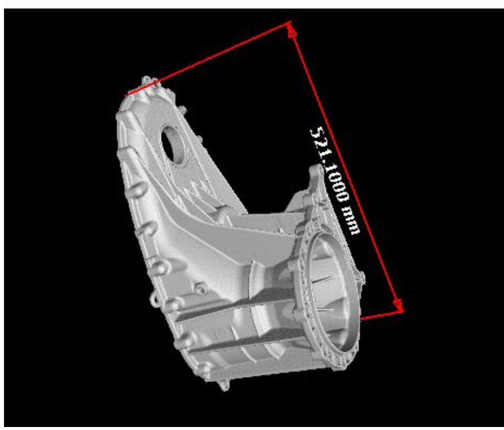
REAL WORLD EXAMPLES

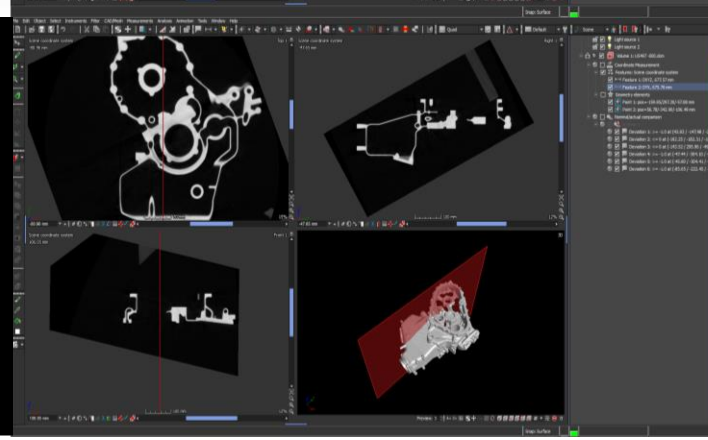
LARGE FORMAT METAL PARTS

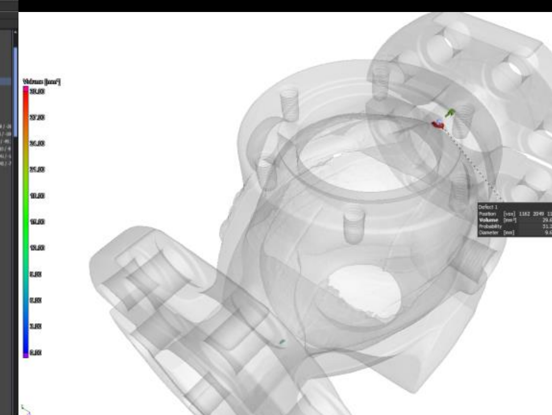








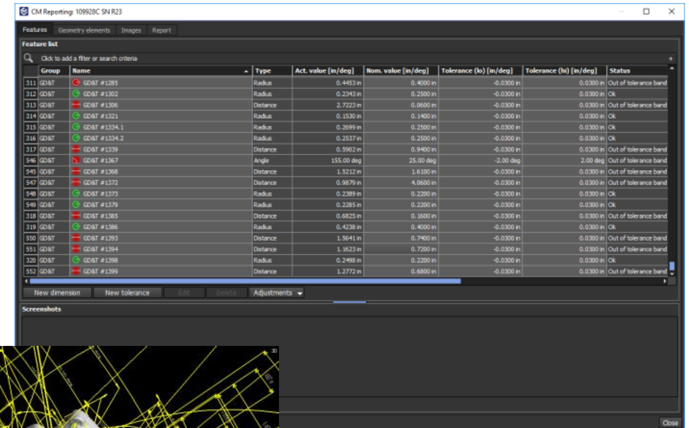




LARGE FORMAT METAL PARTS - MEASURMENTS

Once a part has been scanned, a Part to CAD comparison is first performed and aligned by the part print datums. The developed measurement plan is then executed. Results for every programmed GD&T point are provided in an easy to read chart or in excel format. The first article inspection results show the listed dimension, tolerance, deviation from actual, and value out of tolerance. Within the program, the customer is also able to go to any dimensioned feature and see how the dimension was taken.

- Perfect fit for PPAP or AS9102 form 3 reporting requirements
- Once a measurement plan has been developed and the part has been scanned, tens, hundreds, or thousands of part print points can be dimensioned instantly.
- Complex GD&T callouts such as profile, run out, MMC, LMC, and concentricity can easily be computed
- Complex parts no longer have to be cut up to perform full part print layouts
- Multiple parts can be dimensionally validated faster than traditional inspection methods for a first article PPAP part run



CM Reporting: 109928C SN R23

Features | Geometry elements | Images | Report

Feature list

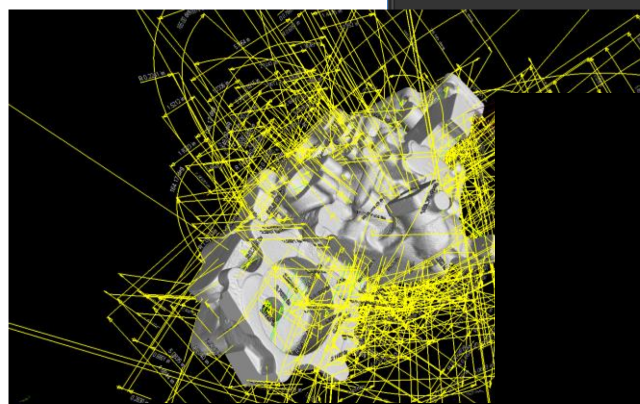
Click to add a filter or search criteria

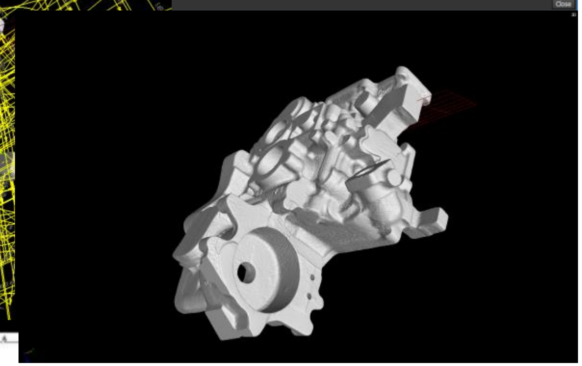
	Group	Name	Type	Act. value [in/deg]	Nom. value [in/deg]	Tolerance (lo) [in/deg]	Tolerance (hi) [in/deg]	Status
311	GD&T	GD&T #1285	Radius	0.4453 in	0.4000 in	-0.0300 in	0.0300 in	Out of tolerance band
312	GD&T	GD&T #1302	Radius	0.2343 in	0.2500 in	-0.0300 in	0.0300 in	Ok
313	GD&T	GD&T #1306	Distance	2.7223 in	0.0600 in	-0.0300 in	0.0300 in	Out of tolerance band
314	GD&T	GD&T #1321	Radius	0.1530 in	0.1400 in	-0.0300 in	0.0300 in	Ok
315	GD&T	GD&T #1334.1	Radius	0.2699 in	0.2500 in	-0.0300 in	0.0300 in	Ok
316	GD&T	GD&T #1334.2	Radius	0.2537 in	0.2500 in	-0.0300 in	0.0300 in	Ok
317	GD&T	GD&T #1339	Distance	0.5902 in	0.9400 in	-0.0300 in	0.0300 in	Out of tolerance band
546	GD&T	GD&T #1367	Angle	155.00 deg	25.00 deg	-2.00 deg	2.00 deg	Out of tolerance band
545	GD&T	GD&T #1368	Distance	1.5212 in	1.6100 in	-0.0300 in	0.0300 in	Out of tolerance band
547	GD&T	GD&T #1372	Distance	0.9879 in	4.0600 in	-0.0300 in	0.0300 in	Out of tolerance band
548	GD&T	GD&T #1373	Radius	0.2389 in	0.2200 in	-0.0300 in	0.0300 in	Ok
549	GD&T	GD&T #1379	Radius	0.2285 in	0.2200 in	-0.0300 in	0.0300 in	Ok
318	GD&T	GD&T #1385	Distance	0.6825 in	0.1600 in	-0.0300 in	0.0300 in	Out of tolerance band
319	GD&T	GD&T #1386	Radius	0.4238 in	0.4000 in	-0.0300 in	0.0300 in	Ok
550	GD&T	GD&T #1393	Distance	1.5641 in	0.7400 in	-0.0300 in	0.0300 in	Out of tolerance band
551	GD&T	GD&T #1394	Distance	1.1623 in	0.7200 in	-0.0300 in	0.0300 in	Out of tolerance band
320	GD&T	GD&T #1398	Radius	0.2498 in	0.2200 in	-0.0300 in	0.0300 in	Ok
552	GD&T	GD&T #1399	Distance	1.2772 in	0.6800 in	-0.0300 in	0.0300 in	Out of tolerance band

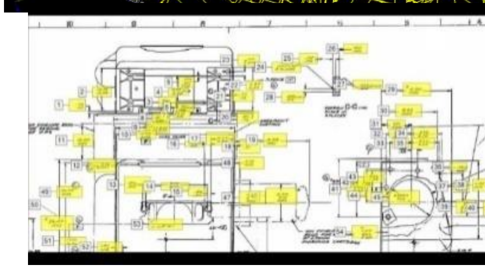
New dimension | New tolerance | Edit | Delete | Adjustments

Screenshots

Close



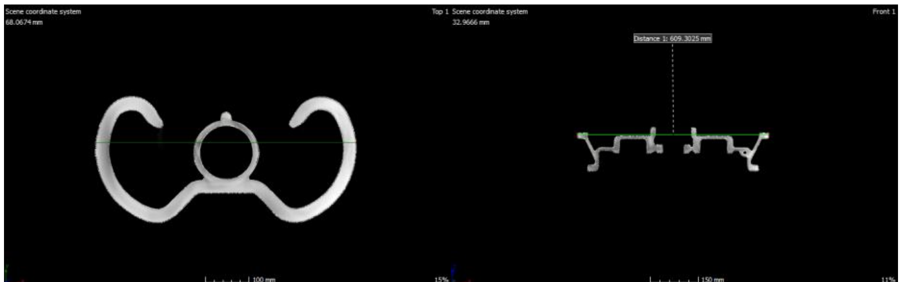


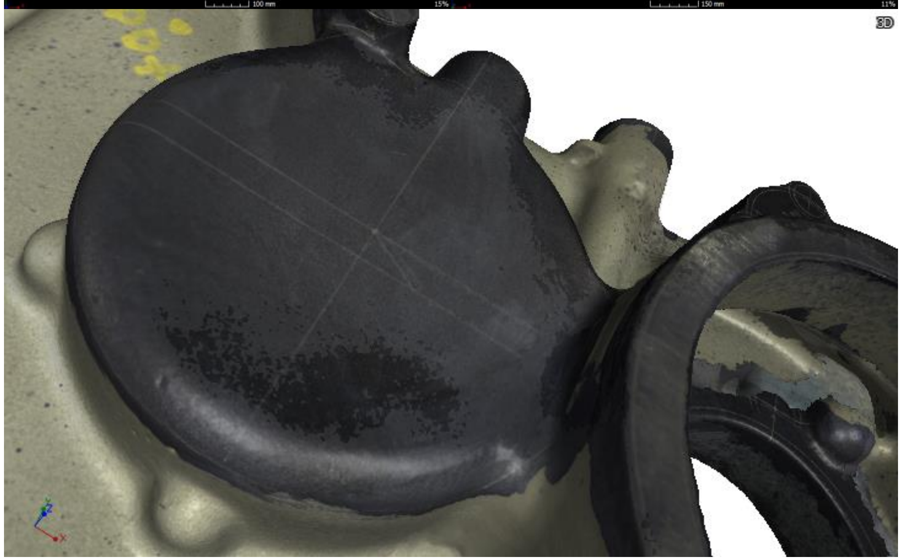


- 1400 Measurements
- 3912 Geometry Elements
- Total time to scan and apply template 80 minutes

**Template previously created

MEASURMENTS – TEXTURES – SCRIBE LINES

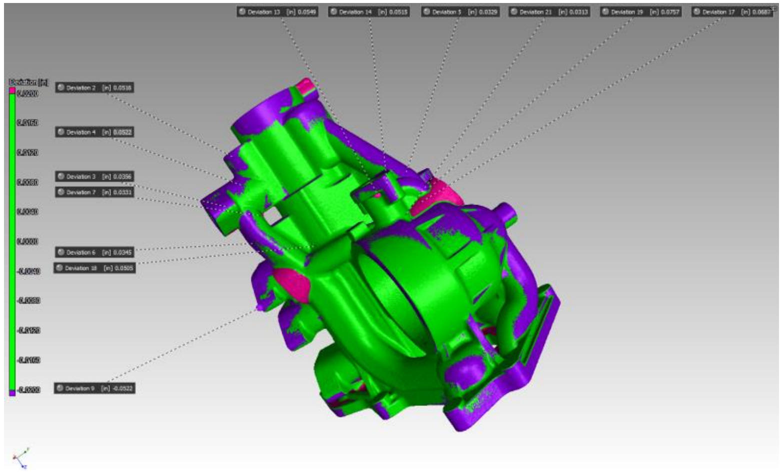


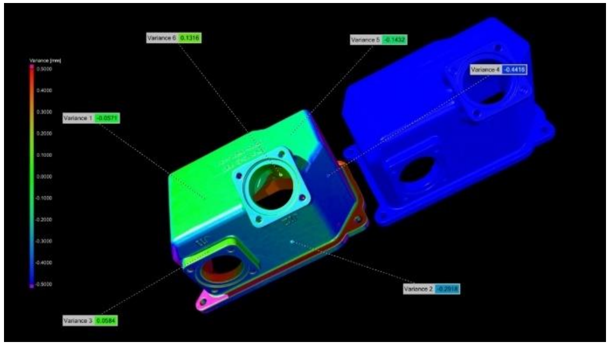


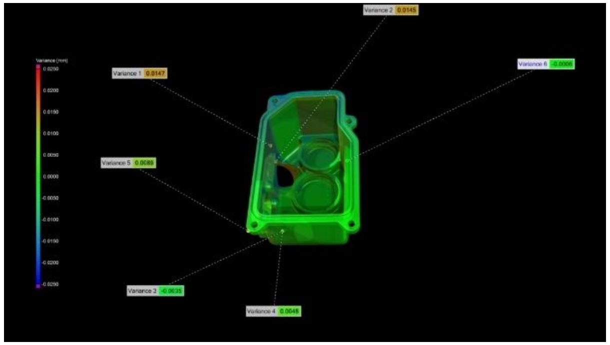
LARGE FORMAT METAL PARTS – PART TO CAD/PART

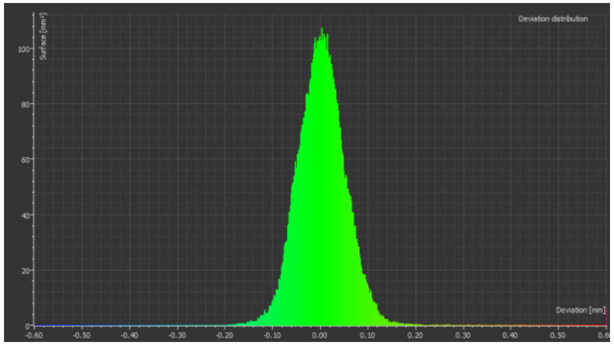
After a part is CT scanned, a supplied CAD model or using another part from the customer the data is compared to the CT dataset. Alignment is performed by either a best fit method or predetermined datum's. Difference are then qualified by:

- The distance between surfaces
- Whisker Plots
- Tolerated Values





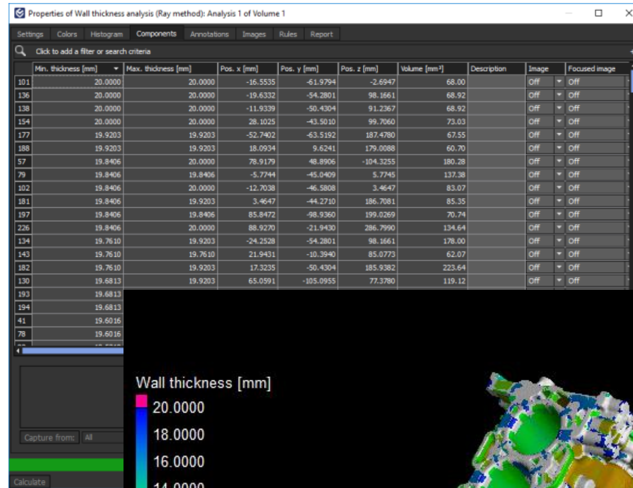




LARGE FORMAT METAL PARTS – WALL THICKNESS

After a part is CT scanned, a ISO surface boundary is created around all internal and external part features. The distance between every surface is calculated and identified as the minimum wall thickness. The results are supplied in a color coded model showing variations from a pre-specified wall thickness.

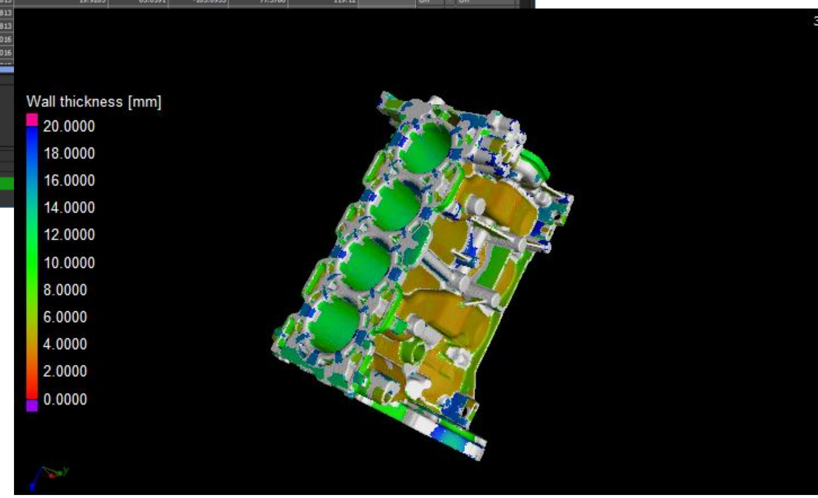
- Results can identify slight variations in a parts wall thickness, which can become costly to the manufacture in high volume part runs
- Results can identify thin walls not meeting the engineered wall thickness sizes for either structural or pressure requirements.

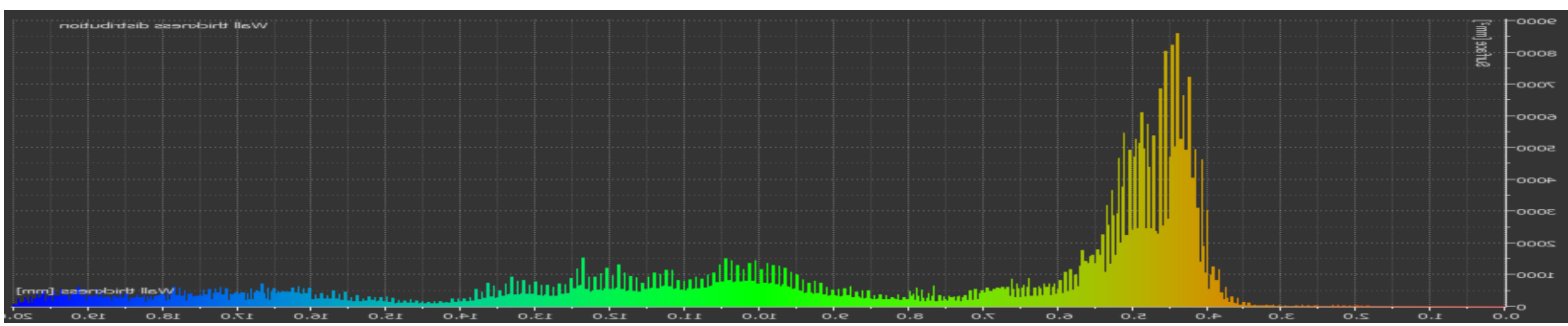

Properties of Wall thickness analysis (Ray method): Analysis 1 of Volume 1

Settings | Colors | Histogram | Components | Annotations | Images | Rules | Report

Click to add a filter or search criteria

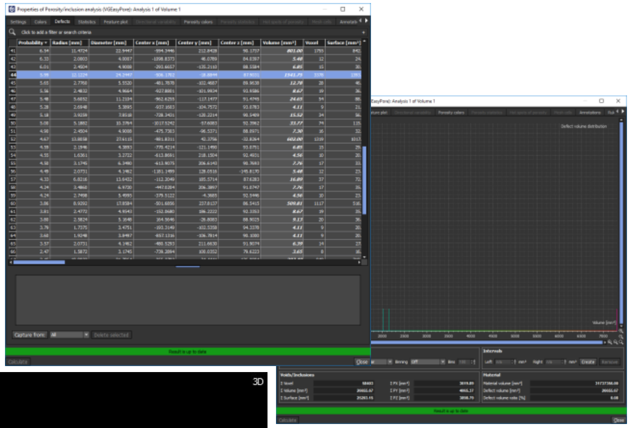
	Min. thickness [mm]	Max. thickness [mm]	Pos. x [mm]	Pos. y [mm]	Pos. z [mm]	Volume [mm³]	Description	Image	Focused image
101	20.0000	20.0000	-16.5535	-61.9794	-2.6947	68.00		Off	Off
136	20.0000	20.0000	-19.6332	-54.2801	98.1661	68.92		Off	Off
138	20.0000	20.0000	-11.9339	-50.4304	91.2367	68.92		Off	Off
154	20.0000	20.0000	28.1025	-43.5010	99.7060	73.03		Off	Off
177	19.9203	19.9203	-52.7402	-63.5192	187.4780	67.55		Off	Off
188	19.9203	19.9203	18.0934	9.6241	179.0088	60.70		Off	Off
57	19.8406	20.0000	78.9179	48.8906	-104.3255	180.28		Off	Off
79	19.8406	19.8406	-5.7744	-45.0409	5.7745	137.38		Off	Off
102	19.8406	20.0000	-12.7038	-46.5808	3.4647	83.07		Off	Off
181	19.8406	19.9203	3.4647	-44.2710	186.7081	85.35		Off	Off
197	19.8406	19.8406	85.8472	-98.9360	199.0269	70.74		Off	Off
226	19.8406	20.0000	88.9270	-21.9430	286.7990	134.64		Off	Off
134	19.7610	19.9203	-24.2528	-54.2801	98.1661	178.00		Off	Off
143	19.7610	19.7610	21.9431	-10.3940	85.0773	62.07		Off	Off
182	19.7610	19.9203	17.3235	-50.4304	185.9382	223.64		Off	Off
130	19.6813	19.9203	65.0591	-105.0955	77.3780	119.12		Off	Off
193	19.6813								
194	19.6813								
41	19.6016								
78	19.6016								

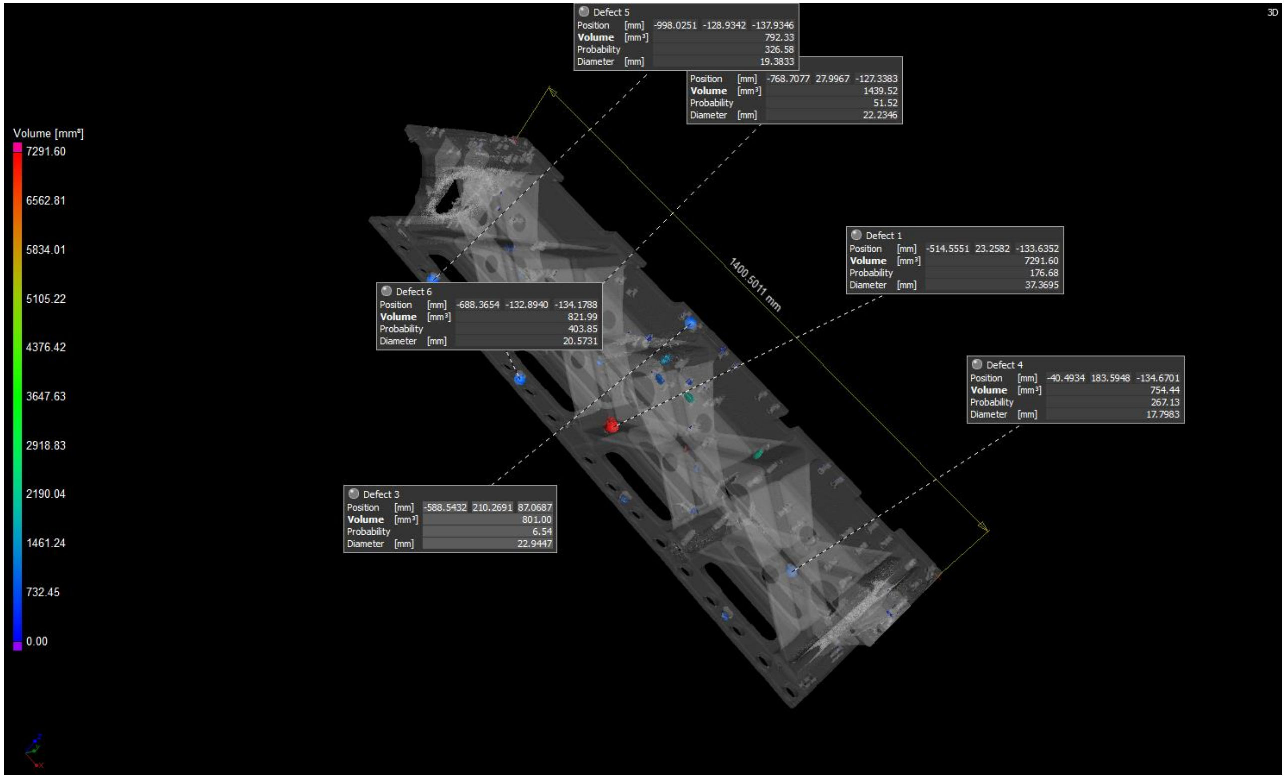




LARGE FORMAT METAL PARTS – VOID/INCLUSION

After a part is CT scanned, a ISO surface boundary is created around the part itself and for each internal porosity within the part. Internal porosity are then quantified by the volume of each pore. Once the volume of each pore has been identified, the results are assigned a color based upon volume and are indexed for easy location identification.





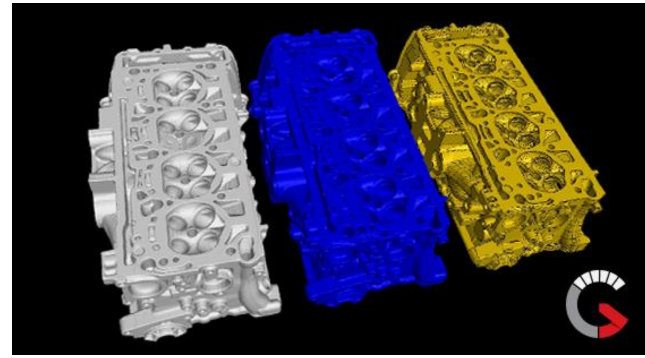
- Results can clearly identify internal porosity and cracks where 2D x-rays show inconclusive or no results
- Results can be quantified by volume and location for each internal void or pore
- Parts no longer have to be cut up to locate internal porosity

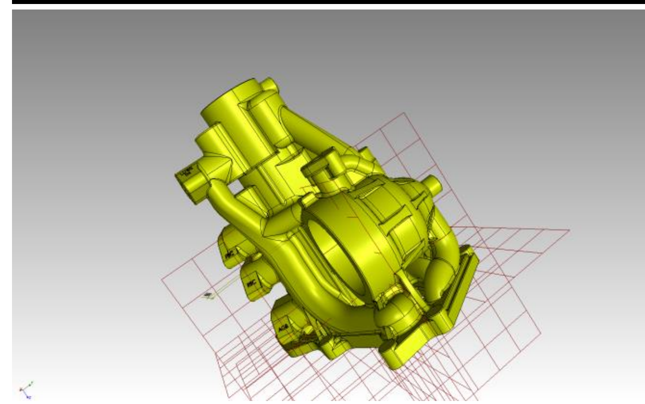
LARGE FORMAT METAL PARTS – REVERSE ENGINEERING

Development of a CAD file with internal and external geometry from a CT dataset. After a part has been CT scanned, internal and external data are extracted from the results. Data can be currently exported in the following formats: STL, WRL, TXT, PLY, OBJ.

Additional Options:

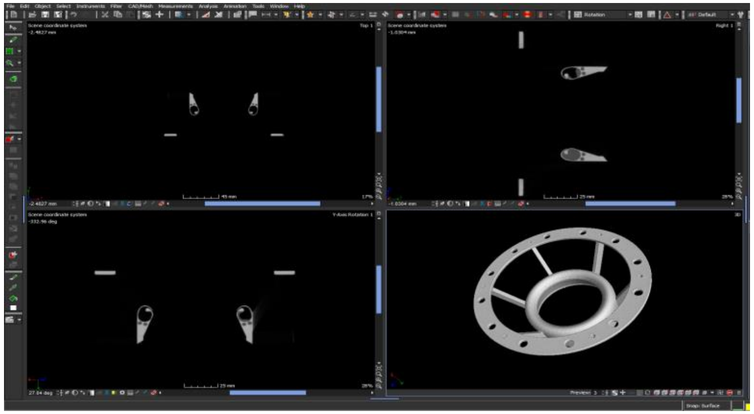
STL To STEP
Point Cloud to Surface Files
FEA Analysis/Mold Flow/
Magma

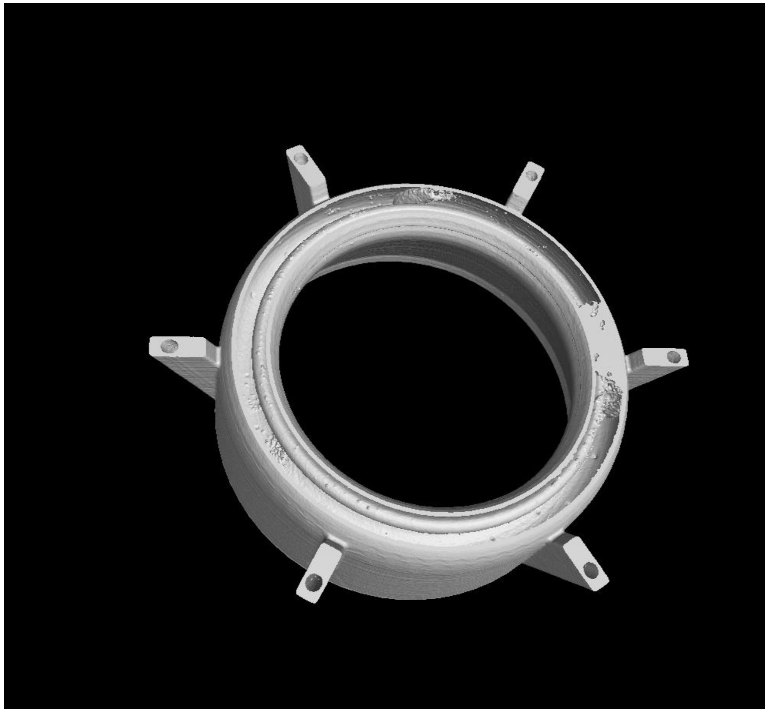


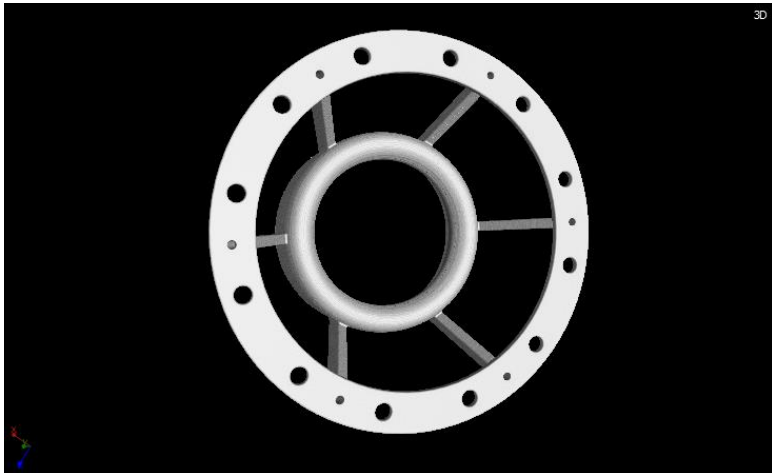


LARGE FORMAT METAL PARTS – AM PARTS

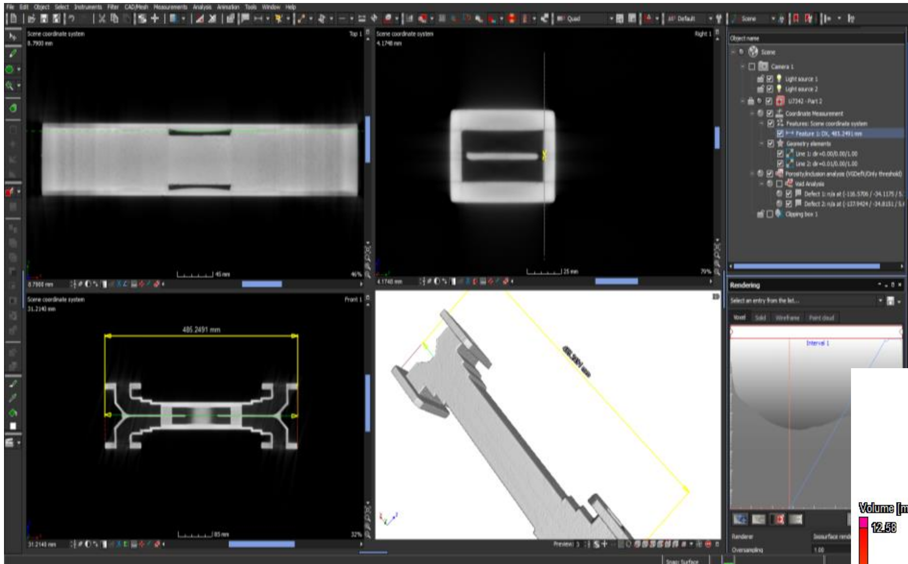
A quick check of a additively manufactured part can determine if there is unfused powder pockets, delamination of layers, keyholing and geometry of internal features.
See images to the right of trapped unfused powder

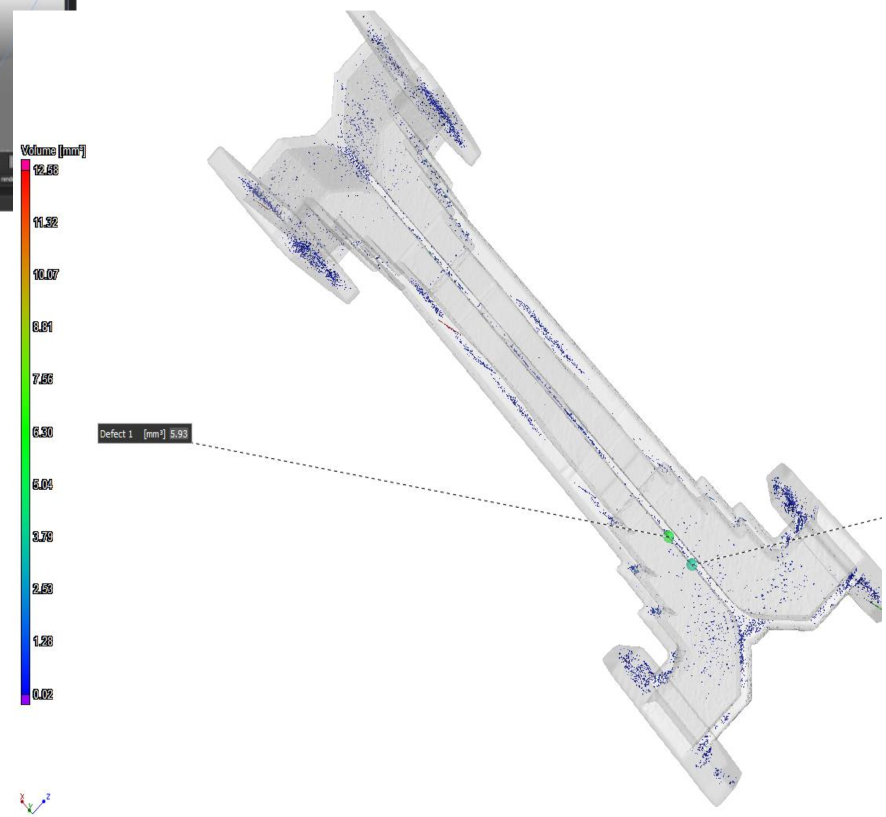






LARGE FORMAT AM PARTS – INCONEL - VOIDS





SUMMARY

Advantage of using a linear accelerators for CT

- Fast acquisition and scan time.
- Large field of view
- Shorter scan times equals less wear and tear on expensive equipment
- More versatility in scanning techniques versus LDAs
- Clean differentiation between mixed materials and complex assemblies.
- High level of resolution and accuracy
- Large higher density and low density materials that cannot be scanned using traditional tubes <1MeV

Special thanks to Tony Melton from Industrial Imaging Solutions and his ZxAcquire DDA Software.