Industrial Production Process Control with Advanced Fan and Cone Beam as well as Helix Computed Tomography

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Imagination at work
After more than one decade of CT application in R&D and quality labs, industrial CT is now moving to drive productivity directly on the factory floor.

Customer requirements for production CT systems:

1. “A CT system need to cover Failure Analysis/NDT & Metrology application”:

2. “We want to scan cylinderheads & crank cases & turbine blades & fan blades &....“

3. “We need to know & monitor system performance“

4. “We want a reliable and affordable solution and need to have total cost of ownership information”
v|tome|x c 450

- Compact 450 kV CT for production applications
- Optimized workflow for shop floors

v|tome|x m metrology|edition

- Microfocus CT for NDT & Metrology application
- High performance VDI 2630 compliance

CT solutions for industrial process control

blade|line

- Fast and accurate 450 kV fan beam CT
- Inspection and measurement of blades
Productivity through fast process control
Ultra fast CT with down to 1 min cycle time
Overview

1. A compact high energy CT solution for production process control and quality Labs with GE’s phoenix v\textregistered tome\textregistered x c 450
2. 3D Metrology with CT following the VDI 2630 guideline
3. Fast and accurate turbine blade inspection and measurement with fan beam CT
4. Advanced fast helix Computer Tomography (CT) at Volkswagen Foundry Hanover using speed\textregistered scan atline CT
GE’s phoenix v|tome|x c: A new compact 450kV industrial Computed Tomography system
Typical production CT applications for the v|tome|x c

- Large and complex light metal castings
- Large and complex composites
- Small to medium sized light metal or steel castings
phoenix v\|tome\|x\ c features

**X-ray detectors**
- 16” DXR flat panel and or
- 814 mm linear detector

**Large Scanning area**
- D 500 mm x H 1000 mm

**Granite based Sample Manipulator**
- Up to 3 axis (Y,Z,R)

**450kV Minifocus X-ray tube**
- Outside main cabinet for easy maintenance access

**Motorized door**

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Inspection Technologies
one-button CT: highly automated workflow for production applications

1. Identify part (e.g. Barcode)
2. Initiate CT - Scan process
3. Acquire & process CT data
4. Verify analysis Results
v-tome-x c performance referring to ASTM and VDI standards

VDI 2630 1.3

Metrology performance referring to VDI 2630 determined on a multi-sphere phantom

\[ E_{SD} = 20 + \frac{L}{100} \ \mu m \]

ASTM E 1695

CT image performance determined on 30 mm sphere

CT Resolution (MTF) = 2.5 lp/mm at 133 \( \mu m \) voxelsize

\[ MTF = \text{Modulation transfer function at } 133 \ \mu m \text{ voxelsize, details on the methods are provided in system manual} \]
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GE’s v|tome|x m metrology|edition: Precise 3D measurements referring to VDI 2630 guideline

Imagination at work.
phoenix v|tome|x m – 3D metrology

Industrial CT process control with extremely high accuracy and reproducibility for

Dimensional measurements / wall thickness analyses
Nominal-actual CAD comparison
Reverse engineering / tool compensation
Influence of CT system components on measurement accuracy

X-Ray tube:
Focal spot position:
- Focal-object and
- Focal-detector-Distance

Manipulator:
Linearity of magnification axis

Detector:
Is the detector ideal regarding its geometry?
phoenix v|tome|x m metrology edition:
System features to ensure measurement precision

- Special design to ensure long term stability
- Granite based precision manipulator
- Temperature stabilized tube and detector
- Direct measuring system
- Automatic voxel calibration tool
- Test phantoms and automatic procedures to determine the specific system values
Compensation - Determination of Focal-Object- and Focal-Detector-Distance

\[ L = ppp \cdot \frac{??F}{??F} \cdot \frac{??F}{??} \]

calibrated length

measured length in voxel

\[ \text{wanted: Focal-Object- and Focal-Detector-Distance} \]

- Determination of 2 variables from two functions (measurements)
- Robust results using more than 2 length in the ball bar
Compensation - Adjusting linearity of the magnification axis

Direct Measurement system: $\rightarrow$ high accuracy and reproducibility

Utilizing a Laser interferometer to linearize the axis:

1) Measuring the actual position of the magnification axis and comparing to nominal position (target position)
2) Using the measured deviations to compensate the axis error (linearizing the axis)
Compensation – Detector flatness

1) Acquisition
2) Reconstruction
3) Evaluation of cylinder diameter at different cylinder heights with 3D image processing
4) Determination of “detector bending”

5) Compensation by including the “real” detector shape in the reconstruction algorithm
Compensated Measurement Results

Distance error of sphere centers, SD [mm]

Non compensated

Incl. compensation

Threshold value for Sphere distance error - v |tome|x m “metrology | edition“:
\[ SD_{MPE} = 4 \mu m + L/100, \ L: \text{nominal length in mm} \]
Conclusion

• Sphere distance error at 80 µm voxel size
  NON compensated 15 µm
  Compensated 2 µm

• Compensation of detector and magnification axis lead to much better results regarding the systems metrology performance

• System-Characteristics following VDI 2630-1.3 in mode “Measurement in the image” (Static):

\[
\begin{align*}
SD_{MPE(TS)} & = 4 \mu m + L/100 \\
PS_{MPE(TS)} & = 3 \mu m \\
PF_{MPE(TS)} & = 3 \mu m
\end{align*}
\]

• Understanding the key system components like tube, detector and manipulation system in detail gives the opportunity to improve the metrology performance following VDI 2630 significantly by compensating the effects
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GE’s blade line CT:
Fast and accurate turbine blade inspection and measurement with fan beam CT

Imagination at work.
MAI Affordable CT initiative

**Technology driver:**

Engine performance requirements become more stringent. High performance engines utilize cooling schemes with advanced multi-wall casting technology.

**Inspection problem:**

State of the art measurement technologies (UT) are not capable of determining the acceptability of these new multi-wall castings.

**Conclusion:**

The advances in turbine engine component design (multi-wall blades) drive a clear need for CT technology.

*Image of simulated PITv2 blade with artificial multi-wall structures*
bladelline setup

Robotic sample manipulation

ISOVOLT Titan
450 kV X-ray source

Turbine blade

GE Jupiter linear detector array

X-ray fan beam

Acquisition of slice projections

Reconstruction of the CT slices

Wall Thickness Analysis

DICONDE data management
blade|line CT inspection workflow

Start

Load part tub 2 with max. 25 Blades outside the cabinet

Open Sliding door manually

Change part tub 1 with part tub 2

Manual input of the Blade ID’s (Hand scanner)

Close Sliding door by manually

Grip Blade n.. with Robot

CT slice Inspection of selected Positions / Blade

Load Blade n.. back to part tub
Workflow- Wall thickness measurement
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GE’s speed|scan CT technology: Automated high-speed CT for 3D mass production process control

Imagination at work.
speed|scan CT 16 implemented in the VW foundry

Technical data

<table>
<thead>
<tr>
<th>Type:</th>
<th>Gantry CT based on modified GE Healthcare technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source:</td>
<td>140 kV (53 kW) dual spot, rotating anode tube</td>
</tr>
<tr>
<td>Detector:</td>
<td>16 lines, 912 channels</td>
</tr>
<tr>
<td>Cabinet:</td>
<td>Full protection radiation cabinet with AC &amp; dust protection</td>
</tr>
<tr>
<td>Manipulator:</td>
<td>Optimized belt drive for fast load/unload and part manipulation</td>
</tr>
<tr>
<td>Measurement volume:</td>
<td>approx. 300 x 400 x 800 mm</td>
</tr>
<tr>
<td>Voxel resolution:</td>
<td>approx 0.5 x 0.5 x 0.5 mm (typical cylinder head)</td>
</tr>
</tbody>
</table>
History of atline speed|scan at Volkswagen

Inspection history of atline speed|scan CT system at Volkswagen:

- Installation of atline CT system: May 2013
- Start of inspections: June 2013
- Number of inspections 2013: 6,700
- Number of inspections 2014 until September: 16,900

Layout location on the foundry production shopfloor:
- 20 m from the prototype foundry;
- 30 m from production line and pouring area
Applications and benefits for fast atline CT

**Features:**

1. Rapid testing and automatic results for main deviations
2. Shorter period to production readiness for new parts
3. **Quicker process optimization, based on statistics**
4. Reduced reject rate in series

**Function modes**

1. Rapid scanning of known serial parts with automatically evaluation, helix scan for 5 known deviations in a short sequence
2. Axial scan with manual evaluation for new parts, scan time 5 min, individual evaluation sequence 20 min.

Dr. R. Rösch, Dr. F. Hansen, F. Jeltsch, VW Foundry Hannover, Germany
Dr. O. Brunke, GE Sensing & Inspection Technologies GmbH, Ahrensburg/Wunstorf
Successful automatic ADR*-evaluation of cylinder heads with GE’s speed|ADR

Automated evaluation of deviations

ADR*: Automatic Deviation Recognition

Dr. R. Rösch, Dr. F. Hansen, F. Jeltsch, VW Foundry Hannover, Germany
Dr. O. Brunke, GE Sensing & Inspection Technologies GmbH, Ahrensburg/Wunstorf
Successful automated evaluation of wall thickness with Volume Graphics Software

<table>
<thead>
<tr>
<th>Σ Teile</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anz. D.O.</td>
<td>8 80.0%</td>
</tr>
<tr>
<td>Anz. a.O. &lt; 3 mm</td>
<td>2 20.0%</td>
</tr>
</tbody>
</table>

Streuung | 2.3 |
Mn. | 2.8 |
Max. | 5.1 |

### kleinste WD in den ausgewählten Bereichen nach CAD: 6,0 mm

<table>
<thead>
<tr>
<th>Ebene</th>
<th>74-1</th>
<th>74-2</th>
<th>186-1</th>
<th>186-2</th>
<th>186-3</th>
<th>186-4</th>
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<th>257-2</th>
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<tbody>
<tr>
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<td>0.0</td>
<td>0.0</td>
<td>2.9</td>
<td>2.7</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
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<tr>
<td>Min.</td>
<td>6.3</td>
<td>6.0</td>
<td>3.3</td>
<td>3.3</td>
<td>5.8</td>
<td>5.7</td>
<td>6.3</td>
<td>5.8</td>
<td>5.8</td>
<td>5.4</td>
</tr>
<tr>
<td>Max.</td>
<td>6.3</td>
<td>6.0</td>
<td>6.2</td>
<td>5.5</td>
<td>5.8</td>
<td>5.7</td>
<td>6.3</td>
<td>5.8</td>
<td>5.8</td>
<td>5.4</td>
</tr>
</tbody>
</table>

### Formel Eingabe Eingabe Formel Korrekturwerte: alle Maße inkl. WD-Zugabe! (Korrekturwerte je Bereich unterschiedlich)

<table>
<thead>
<tr>
<th>Formel</th>
<th>Eingabe</th>
<th>Eingabe</th>
<th>Formel</th>
<th>Korrekturwerte</th>
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<tbody>
<tr>
<td></td>
<td>CT-Nr.</td>
<td>Teil Nr.</td>
<td>min. WD</td>
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<tr>
<td>i.O.</td>
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<td>991</td>
<td>5.1</td>
<td>6.3</td>
</tr>
<tr>
<td>i.O.</td>
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<td>1000</td>
<td>5.1</td>
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<tr>
<td>i.O.</td>
<td>4</td>
<td>960</td>
<td>3.3</td>
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<tr>
<td>n.i.O.</td>
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<td>1065</td>
<td>2.8</td>
<td>6.3</td>
</tr>
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<td>i.O.</td>
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<td>5.1</td>
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<td>n.i.O.</td>
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</tr>
<tr>
<td></td>
<td>12</td>
<td>1055</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Detection of sandcores in waterjacket

Before optimization: residual sandcores detected

Successful change of parameters – no remaining pieces of sandcore
Task reducing deformation of waterjacket: 2.6 mm

VG Inline, automatically generated result
Deformation of waterjacket reduced to:
1.1 mm
VG Inline, automatically generated result
Second correction step – no deformation of waterjacket

VG Inline, automatically generated result
Pores as result of correcting parameters against deformation

VG Inline, automatically generated result
End of optimization - no deformation and no pores
Summary: Successful applications for fast atline CT

Extraction of features – Wall thickness measurements – Deviation detection

Different quantitative and qualitative inspections are possible
Coming soon: speed|scan CT 64

- Down to 1 minute cycle time with highly automated workflow
- Scanning volume up to $\varnothing$ 500 x 900 mm
- Several hundred times faster than conventional industrial fan beam CT and 4x faster than speed|scan CT 16
- Robust design for harsh industrial environments
- GE’s 3D speed|ADR software
- Quick process optimization based on statistics
- Reduced reject rates in series

Providing Healthcare for the Industry
Learn more about industrial CT innovations at GE booth 723 in the exhibition area.