SIMULATION OF ULTRASONIC, EDDY CURRENT AND RADIOGRAPHIC TECHNIQUES WITHIN THE CIVA SOFTWARE PLATFORM

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OUTLINE

- Introduction
- UT simulation
  - Coarse grain structures
  - 3D CAD geometry
- ET simulation
  - Simulation with combined flaws
  - GMR’s sensors
- RT simulation
  - Generalities
  - Weld inspection
- Conclusion
Introduction

<table>
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<tr>
<th>Use of simulation in NDT</th>
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<tr>
<td>- Design of new methods and probes (e.g. phased arrays)</td>
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<td>- Qualification of methods, performance demonstration</td>
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<td>- Interpretation of complex results, automatic diagnosis</td>
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<td>- « Virtual testing » at the designing stage of parts</td>
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<td>- Training</td>
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<table>
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<tr>
<th>Development of the CIVA software by CEA-LIST and partners</th>
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<tr>
<td>- Multi-technique platform: UT, ET and RT</td>
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<td>- Used by more than 130 companies in the world</td>
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<td>- Validation within international benchmarks</td>
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| Distributed by EXTENDÉ CIVA |

| This presentation: new skills in UT, RT, ET simulation with CIVA 10 (to be released by end of June) |

http://www-civa.cea.fr  
http://www.extende.com
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Conclusion
UT: Coarse grain structures

Motivation
- Detection and characterization of defects in Centrifugally Cast Stainless Steel components (CCSS)

Background
- Inspection difficulties due to the particular metallurgical structure of such materials
  - large grains (up to 20 mm)
  - heterogeneous equiaxed / columnar structure
  - stratified structure

Strong variability of the echoes depending on the transducer position
UT: Coarse grain structures

**Modeling Approach**

1. **Structure description using Voronoï diagrams**
   - Equiaxed structure in a planar specimen
   - Columnar structure in a cylindrical specimen

2. **Description of elastic properties**
   - Isotropic elastic material properties
   - Velocity values (VL) for each cells are fixed randomly by using a uniform distribution
   - $V_L$ randomly fixed for each macro-grain

Velocity values ($V_L$) for each cell are fixed randomly by using a uniform distribution: $V_L \text{min} \leq V_L \leq V_L \text{max}$.
UT: Coarse grain structures

- Focused probe, 1 MHz, 0° L-waves
- Voronoï description: 800 cells (mean size ~10 mm), DVL=3%

Coarse structure
Homogeneous steel
UT: Coarse grain structures

**Back-wall echo measurement for various probe positions**

**Back-wall echo measurement setup**

**Inspection setup**

- $L_0$
- 1 MHz
- $H_{\text{water}}=150$ mm
- $P_{\text{focus}}=70$ mm

**External radius**: 417 mm

**Probe displacement along the cylinder axis**

**Back-wall echo simulation**

**Voronoi diagram**

- # cells = 1500
- Mean cell size $\approx 12$ mm

**Displacement**: 0-250 mm

$\Delta V_L=0\%$

$\Delta V_L=3\%$
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UT: Flaw detection in 3D CAD test pieces

Use of a phased array sectorial technique for detection of a crack close to the vertical wall (no available scanning close to the edge)

Meshed specimen

Tilted flaw (semi-elliptical shape)

UT simulation accounts for:
- Longitudinal + Transverse + Converted Modes
- Echoes of the specimen boundaries + interaction with the flaw
UT: Flaw detection in 3D CAD test pieces

UT simulation result with back wall + flaw echoes (all L and T modes)
UT: Flaw detection in 3D CAD test pieces

Interpretation: comparison between computation with and without the flaw

<table>
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<th>UT simulation WITHOUT flaw: only geometrical echoes</th>
<th>UT simulation WITH a flaw: geometrical echoes + echoes from the flaw</th>
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- Tip diffraction
- Corner echo:
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ET: Simulation with “Combined” flaws

- CIVA 10 allows defining several flaws in a given configuration
- Interactions between various flaws are accounted for
- Typical configurations are as following:
  - Plates
  - Tubes
  - Riveted structures
    - 2 layers with conductivities $\sigma_1$ and $\sigma_2$
ET: Simulation with “Combined” flaws

SIMULATION example

- Frequency 100 kHz
- Inconel plate
- Flaw n°1: 100% thickness
- Flaw n°2: 50% thickness
ET: Simulation with “Combined” flaws

Experimental Validation

Defect 1: 100% thickness

Defect 2: Surface breaking defect 40% thickness

Inspection: 300Khz
ET: Simulation with “Combined” flaws

Experimental Validation

Simulation

Experiment

Real part Imaginary part

Real part Imaginary part

Real part Imaginary part

Real part Imaginary part

-17 mm 7 mm

-17 mm 7 mm

-17 mm 7 mm

-17 mm 7 mm

-17 mm 7 mm

-17 mm 7 mm

-10.257 mm

-10.257 mm

-10.257 mm

-10.257 mm

-10.257 mm

-10.257 mm

1.05 E3 mV

5.0515E-3 mV

1.230 mV

17.0883 mV

-0.099 mV

-0.668 mV

Palettes : Dégradés de couleur
Forme : Linéaire
Max : 1.05 E3 mV
Min : -0.099 mV

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ET: Magnetic probes, GMR sensors

Principles of GMR (Giant Magneto Resistance) sensors

- **Free layer**: magnetization depends on applied magnetic field
- **Pinned layer**: fixed orientation of the magnetization
- **Thin conductor layer**

**Variation of the resistance as a function of the applied field**

**Two major advantages:**

- **Very high sensitivity**
  - (at low frequencies: better than classical coil)
  - 1. Detection of buried defects
- **Small sensors (<~ mm²): high resolution**
  - 2. Detection and separation of small flaws
ET: Magnetic probes, GMR sensors

SIMULATION of GMRs with CIVA software

Stream lines visualisation
ET: Magnetic probes, GMR sensors

SIMULATION of GMRs with CIVA software

Electric Field visualization
ET: Magnetic probes, GMR sensors

SIMULATION of GMRs with CIVA software

Defect Response

- **Bx** configuration (amplitude)
- **By** configuration (real part)

**Inspection settings:**
- Flaw = 100 µm³
- Frequency = 1 MHz
- Current foil = 10x30 mm²
- Sensor’s lift-off = 200 µm

- Good agreement simulation/experiment
- ECT response shape varies according to the orientation of the GMR: potential defect characterization
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RT: Generalities

- Mix of two models implemented since CIVA 9 in order to enable in CIVA the best features in Gamma and X-Ray
- Develop a Collaborative platform to integrate a new code architecture global to Radiola’s partners (European project).
- Create a powerful global RT simulation software combining the best software already developed in France
- Part of Radiola’s project has been integrated onto CIVA 10.0 version

CIVA 10 and further

- New tools for the Monte-Carlo simulation:
  - Parallelization of the Monte-Carlo computation is now available
  - Possibility to re-load a previously computed Monte-Carlo result
- Integration of new visualization tools
- Thanks to the new architecture, integration of new kinds of specific detectors is quite easy for the future
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RT: Bi-metallic Weld inspection

Bi-metallic weld with a complex crack

Detector (green part) + wire IQI

Ferritic steel

Stainless steel

Inconel
RT: Bi-metallic Weld inspection

Bi-metallic weld with a complex crack

Inspection settings:
- Source: Ir192, Activity 5000 Gbq
- Exposure time: 2h
- Detector: 1mm of AgBr...
- Distance Source / Detector: 300 mm
RT: Bi-metallic Weld inspection

Bi-metallic weld: Simulation WITHOUT FLAW

Build up image
Mean value 4.9

Detector response
RT: Bi-metallic Weld inspection

Bi-metallic weld: Simulation WITH FLAW

Build up image
Mean value 4.9

Detector response

Crack
Rectangular flaw
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- Simulation codes for UT, ET and RT are gathered within the same software platform: CIVA

- NDT realistic inspections can be simulated within the CIVA platform for those three techniques

- CIVA 10 version released by end of June 2010

- Simulation capabilities widely extended in this major version

- Experimental validations carried-out to ensure reliability of CIVA simulations

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