Validation of the simulation of pipeline girth welds PA UT inspections

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Context

Scope of work for this study

Modeling the calibration mock up

Modeling the qualification defective welds

Conclusion
Context

- Zonal discrimination method for pipeline girth welds inspection:
  - Currently used for 1 or 2 decades by oil & gas industries
  - Includes multi-channel UT acquisition systems:
    - Phased-Array
    - Conventional multiple probes
  - Division of the weld into different zones (max. 3mm height)
  - Each channel inspects one zone: UT beam is focused and temporal acquisition gates are sized to collect only data from one zone per channel
Before commissioning, 3rd party qualification of AUT systems and procedures is required *(based on DNV standards: “OS F101” & Recommended practice “DNV RP F118”)*.

TOTAL specific qualification program *(GS EP PLR 430)* shall be carried out following 2 main steps:

- **Calibration** on a mock-up including various reflectors (FBH, Notches) in the different zones: Static & Dynamic calibration, repeatability tests, etc.
- **Performance evaluation tests**: Welds with realistic defects:
  - Validation of AUT results (detection and sizing) with macrographs obtained from “salami” cuts (maybe also RT and manual UT for cross-verification)
  - PoD and sizing accuracy curves
Context

Potential limits of the current fully experimental approach:

- The whole qualification process is costly and time consuming (calibration mock-ups, create defective welds, take macrographs)
- Strong dependance for the PoD and sizing accuracy curves on the available flaws in the welds: Is it really reliable?
- Not possible for available flaws to cover all possible skew, tilt, position & size variations
- Difficult to evaluate the impact of influential parameters such as:
  - System mechanical position on pipe (i.e. real distance to the weld fusion line and centerline)
  - Uncertainties on probe and system settings

Modeling could help increasing qualification level, improve reliability of results…while reducing time and costs!
Scope of Work

- Final goal: Replace some parts (but not all!) of the experimental tests
- Goal of this study: Validate results obtained with simulation versus real acquisition data
- Once confident in simulation, experimental results can be confirmed and complemented with simulated ones

Data extracted from a real project qualification report
- Pipelines: OD 48”/WT 26.8 mm
- 1° J-bevel weld profile:
Scope of Work

PA UT System qualified in the “real project”:

- PipeWIZARD® from Olympus
- Includes mainly 1 phased-array probe on each side (upstream, downstream) with rexolite wedge (also TOFD and single element channels)
- Operating frequency: 7.5 MHz
- 22 channels on each side, 10 have been selected for this study to cover Pipe Wall Thickness:
  - Root and Hot-Pass zones: R1U (Root1 Upstream), R2U, H1U
  - Fill zones (fusion line): F1U, F2U, F7U
  - Cap zone: FC1U, FC2U
  - Volume zone: V3U, V3D
- System rotates mechanically around pipeline circumference
Simulation software: CIVA

Dedicated NDE modeling tool

Multi-techniques:
- UT: Ultrasound
- GWT: Guided Wave
- ET: Eddy Current
- RT: Radiography
- CT: Computed Tomography

Semi-analytical models

Developed by CEA (French Atomic Energy commission: Research center)

Distributed by EXTENDE worldwide and by EXTENDE Inc. in the US/Canada

Used by more than 190 companies worldwide
Scope of Work

- To have complete & precise inputs: Often a difficult task!
- Required input data for simulation studies:
  - Pipe, mock-up and weld properties (detailed drawing, density & bulk wave velocity, reflectors description and associated channel)
  - Probe characteristics (frequency, array type, number and size of elements, index point, wedge properties)
  - Focal laws (active groups, delay laws, index point)
  - Positioning, acquisition step, temporal gates
  - Detailed experimental results…to be able to compare
- In our study, main source of uncertainties were:
  - Actual delays in the system: Delay values not available → Were recalculated by CIVA based on focal law settings
  - 1st active element in a group: Can slightly changes vs qualif. report
  - Probe positioning on defective welds (Tack welding effects)
Modeling the calibration mock-up

Mock-up description:

- 45 reflectors
- For each channel, one reflector is defined as a reference and amplitude is set to 80% FSH
- Signal amplitudes for adjacent and other flaws estimate the agreement between the model and measurement values
Modeling the calibration mock-up

Example of UT beam simulation with 1 channel

- F2U: Fill 2 Upstream
- Active groups (Separate T/R), ray tracing, and reference FBH:

- Beam profile (CIVA V10 computation):
  - Beam side view: -6dB envelope
  - Beam in the weld plane: -6dB spot sizing: 2.9mm*4.4mm

In accordance with expected spot size for zonal discrimination
Modeling the calibration mock-up

Results: Comparison PipeWIZARD and CIVA charts

- Reference reflector signal set at 80% FSH is framed in yellow

An overall good agreement
Modeling the qualification defective welds

Defects under study (macros from the examination report):
- 5 “real” flaws artificially created in 4 different welds by deviating from welding process:

<table>
<thead>
<tr>
<th>Type of Flaw</th>
<th>Salami cuts Macrograph(s)</th>
<th>View in CIVA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weld1 – Flaw1: Lack Of Fusion 2.5mm</td>
<td><img src="image" alt="Macrograph" /></td>
<td><img src="image" alt="View in CIVA" /></td>
</tr>
<tr>
<td>Weld1 – Flaw2: Burn Through 2.5mm</td>
<td><img src="image" alt="Macrograph" /></td>
<td><img src="image" alt="View in CIVA" /></td>
</tr>
<tr>
<td>Weld2: Lack Of Fusion – 1.3mm</td>
<td><img src="image" alt="Macrograph" /></td>
<td><img src="image" alt="View in CIVA" /></td>
</tr>
<tr>
<td>Weld3: Porosity 3.5mm</td>
<td><img src="image" alt="Macrograph" /></td>
<td><img src="image" alt="View in CIVA" /></td>
</tr>
<tr>
<td>Weld4: Lack Of Fusion - 3 mm</td>
<td><img src="image" alt="Macrograph" /></td>
<td><img src="image" alt="View in CIVA" /></td>
</tr>
</tbody>
</table>
Modeling the qualification defective welds

Simulation case for flaw 1 – Weld 1:

- CIVA Results for Hot Pass1: Simulated D-Scan (Increment/Time) and echodynamic curve (~ PipeWizard chart for 1 channel)

- Simulation of each channel where this flaw is detected (from examination report)
- Amplitudes are extracted
- 61% FSH for H1U
### Modeling the qualification defective welds

Table of results:

<table>
<thead>
<tr>
<th>Weld- Flaw</th>
<th>Channel</th>
<th>PipeWizard Result</th>
<th>CIVA Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weld1 - Flaw1 (LoF)</td>
<td>F1U</td>
<td>73%</td>
<td>48%</td>
</tr>
<tr>
<td></td>
<td>H1U</td>
<td>58%</td>
<td>61%</td>
</tr>
<tr>
<td></td>
<td>R1U</td>
<td>SAT</td>
<td>SAT</td>
</tr>
<tr>
<td>Weld1 - Flaw2 (BT)</td>
<td>F1U</td>
<td>74%</td>
<td>10%</td>
</tr>
<tr>
<td></td>
<td>H1U</td>
<td>66%</td>
<td>57%</td>
</tr>
<tr>
<td></td>
<td>R1U</td>
<td>SAT</td>
<td>SAT</td>
</tr>
<tr>
<td>Weld2 - Flaw 1 (LoF)</td>
<td>R2U</td>
<td>27%</td>
<td>SAT</td>
</tr>
<tr>
<td>Weld3 - Flaw 1 (Por)</td>
<td>F1U</td>
<td>37%</td>
<td>45%</td>
</tr>
<tr>
<td></td>
<td>F2U</td>
<td>24%</td>
<td>119%</td>
</tr>
<tr>
<td></td>
<td>F3D</td>
<td>27%</td>
<td>32%</td>
</tr>
<tr>
<td>Weld4 - Flaw 1 (LoF)</td>
<td>F7U</td>
<td>86%</td>
<td>90%</td>
</tr>
<tr>
<td></td>
<td>FC2U</td>
<td>75%</td>
<td>SAT</td>
</tr>
<tr>
<td></td>
<td>FC1U</td>
<td>SAT</td>
<td>SAT</td>
</tr>
</tbody>
</table>

- **Weld1-Flaw1**: All channels OK (<4dB difference between PW and CIVA)
- **Weld1-Flaw2**: 2 Channels OK & 2 discrepancies:
  - H1U: OK
  - R1U: OK
  - F1U: From available macrographs, “Burn through” limited to the root area, very unlikely that Fill channel gives strong signal: Additional salami cuts probably necessary to describe correctly this flaw
  - R2U: Probably due to the lack of precision for root channels’ delay laws already noticed in the calibration
Modeling the qualification defective welds

Table of results:

- **Weld2-Flaw1**: 1 channel OK and 1 discrepancy
  - F1U: OK
  - F2U: *A second case has been run with a change of 1mm in the index point → strongly improves results
  - Probe to weld distance change between calibration mock-up and defective welds (tack welding effects) were by default not accounted for (due to lack of information)

- **Weld3-Flaw1**: All channels OK

- **Weld4-Flaw1**: All channels OK

An overall good agreement
Conclusion

- PipeWIZARD Phased-array UT inspection of pipeline girth welds has been simulated with CIVA software.
- Two main steps of a real qualification project have been “reproduced”:
  - Calibration mock-up
  - Defective welds (real flaws)
- Results show a good agreement between modeling and experiment: CIVA can be considered as able to simulate such configurations.
- Results demonstrate the importance to master influential input parameters and the high sensitivity of zonal discrimination method to actual probe position and weld geometry (maybe a weak point of the current procedure).
Perspectives

- Extend the validation process to the building of POD and Sizing Accuracy curves

- Towards a rising acceptance of modeling tools in oil & gas industry (such as other sectors):
  - To improve qualification tests reliability while reducing time and costs
  - To help the design and optimization of inspection techniques with simulation studies
  - To ease exchange views between the different contractors in a project (Simulation = Visual support)
  - For operators training and qualification
QUESTIONS ?