Validation of the simulation of pipeline girth welds PA UT inspections

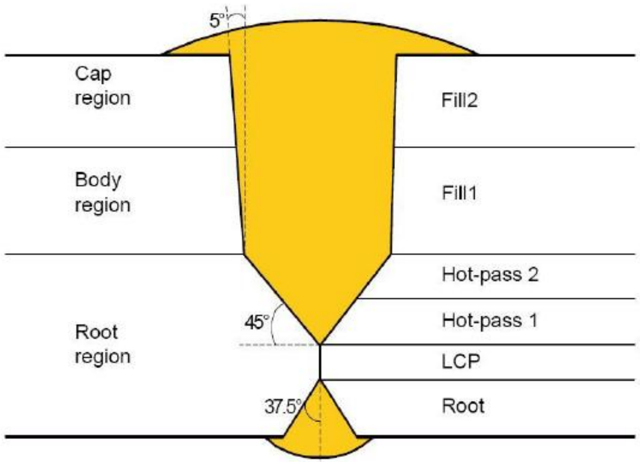
Fabrice FOUCHER, Philippe DUBOIS (EXTENDE), Erica SCHUMACHER (EXTENDE Inc.), Vincent GAFFARD, Henri GODINOT, Henri ROMAZZOTTI, Anne COURBOT (TOTAL)

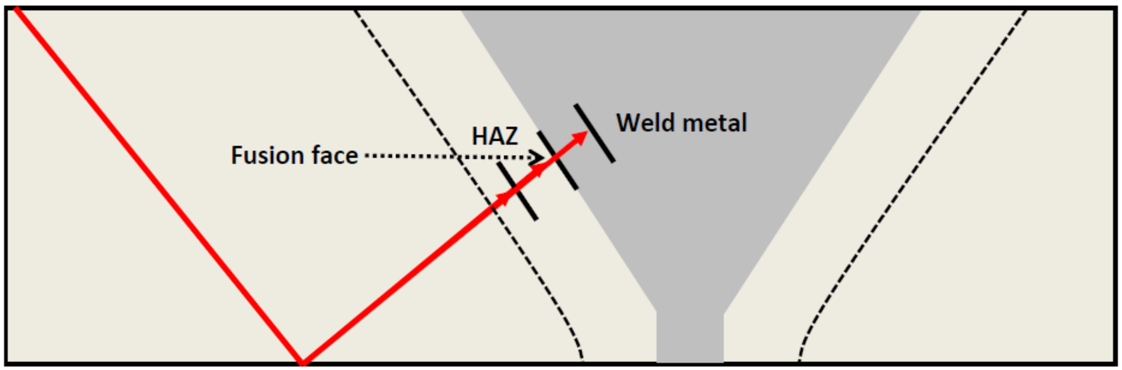
ASNT Fall Conference 2012, Orlando, Florida, USA 31/10/2012

Contents

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





Context

- 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-verifications)
    - PoD and sizing accuracy curves

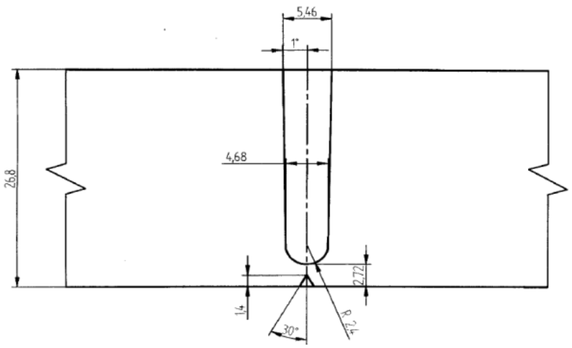
Context

- 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

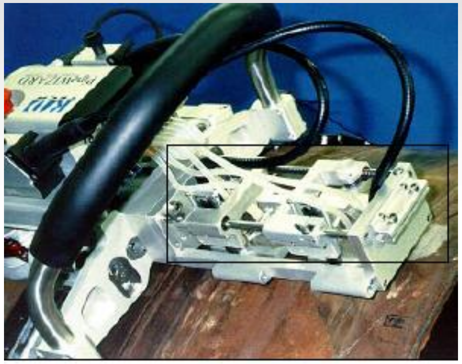
- Final goal: Replace some parts (but not all!) of the experimental tests
- Goal of this study: Validate results obtained with simulation versus real acquisition data
- Once confident in simulation, experimental results can be confirmed and complemented with simulated ones

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



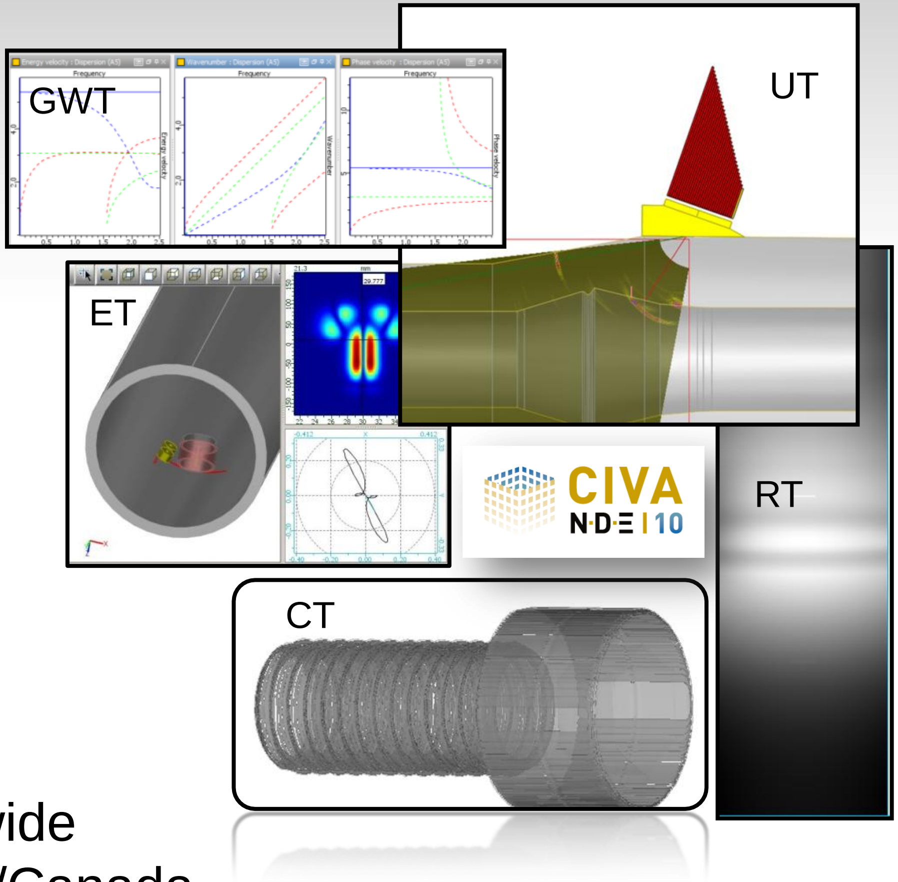
Scope of Work

- 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



Scope of Work

- 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
- Developped 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

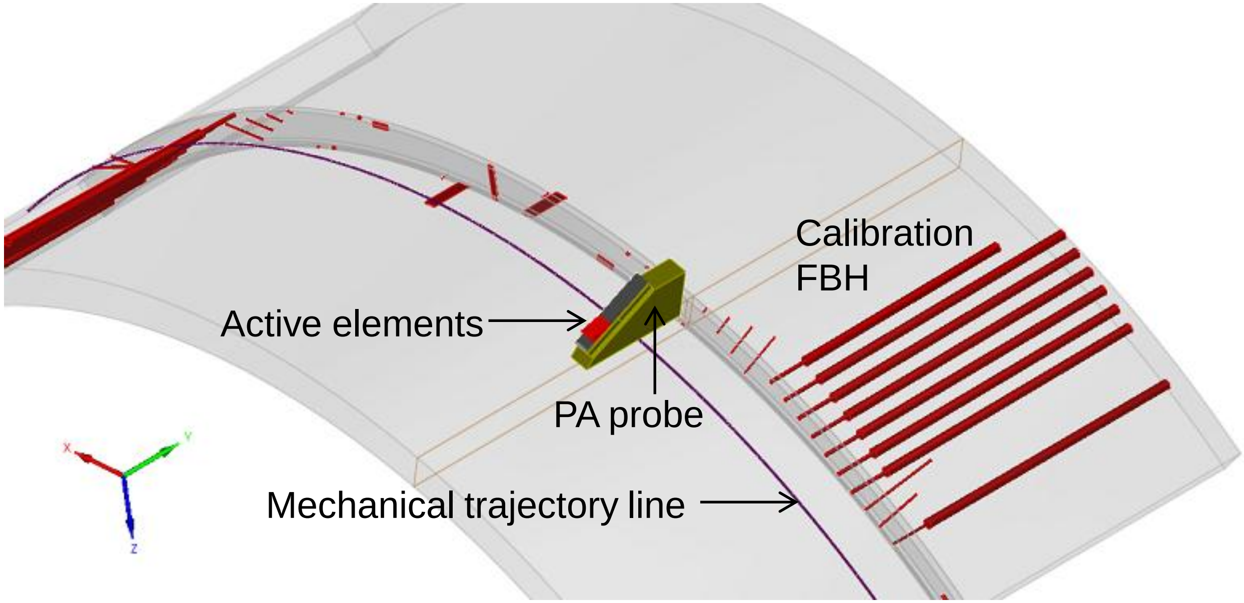


Scope of Work

- 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
  - <u>Detailed</u> 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)

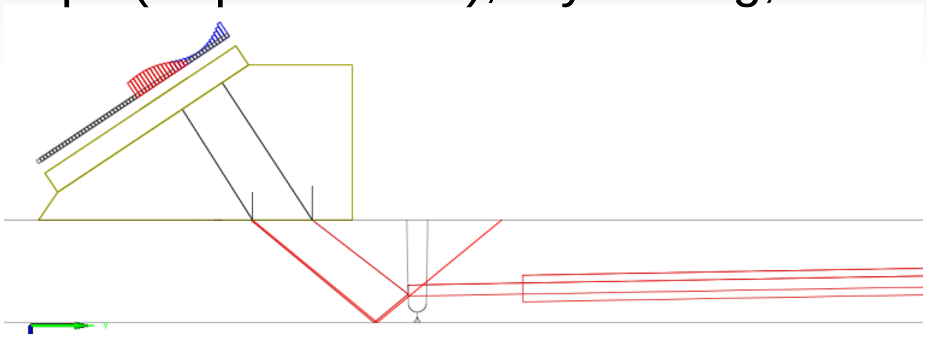
Modeling the calibration mock-up

- 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

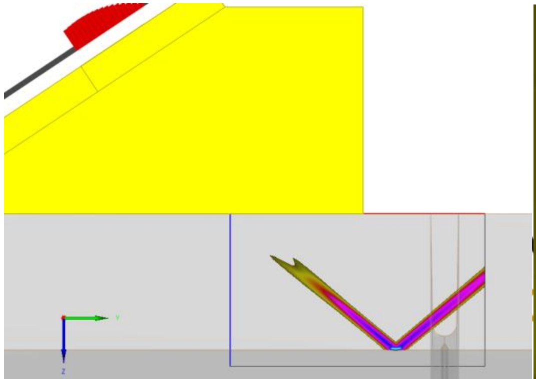


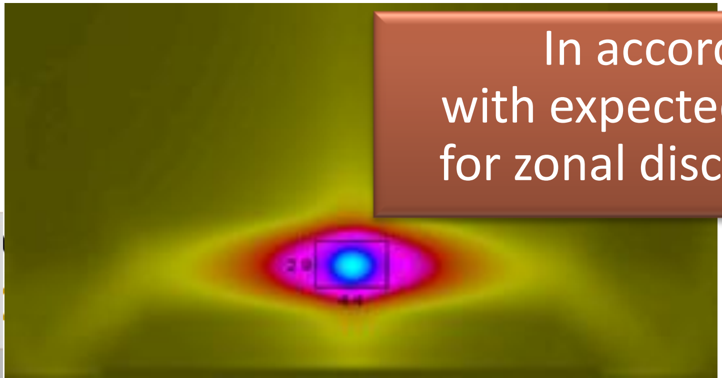
Modeling the calibration mock-up

- 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

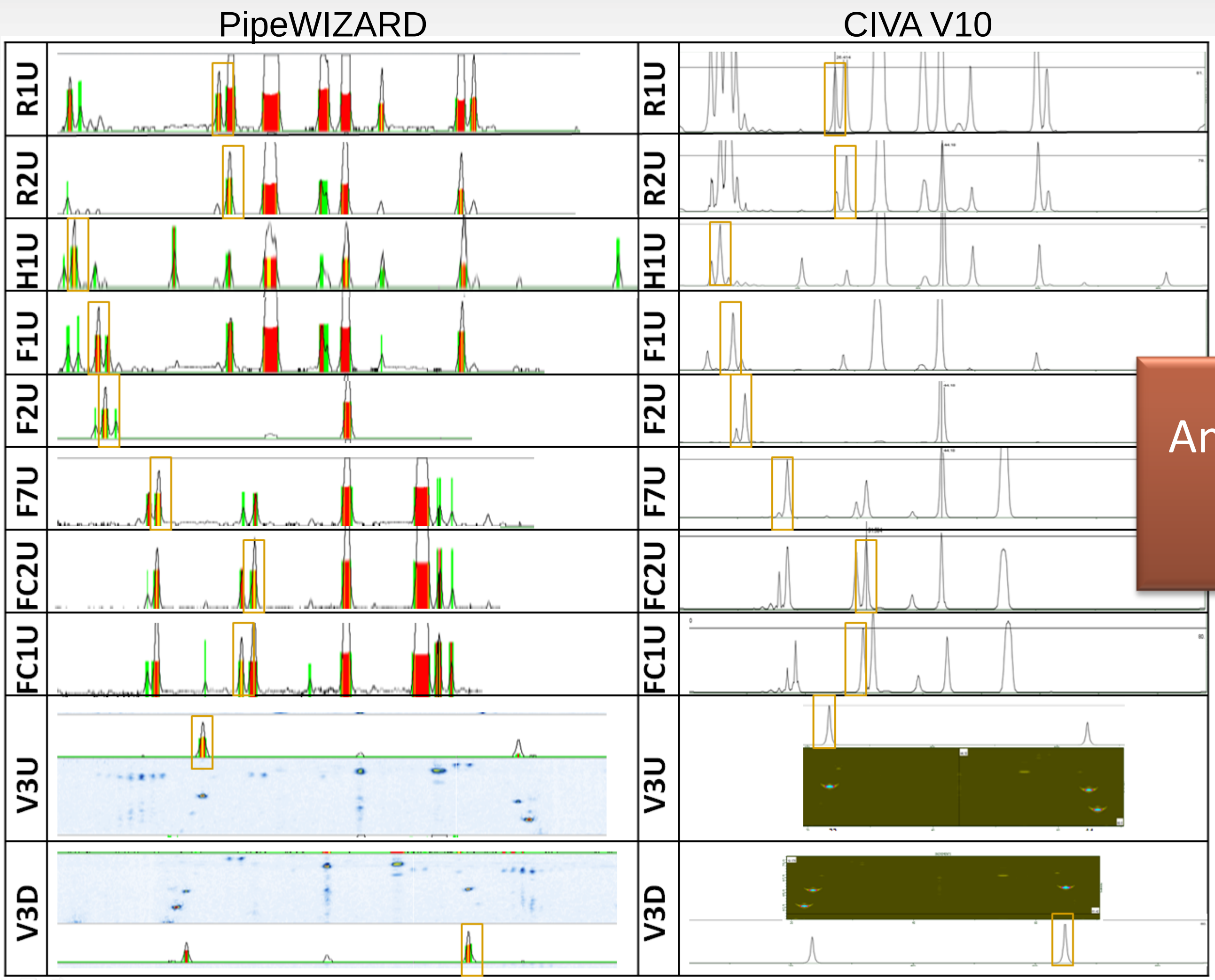




In accordance
with expected spot size
for zonal discrimination

Modeling the calibration mock-up

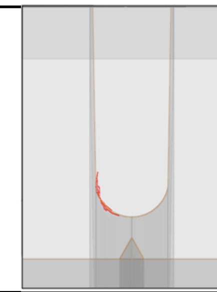
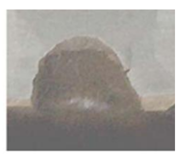
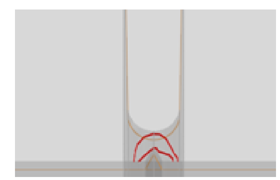
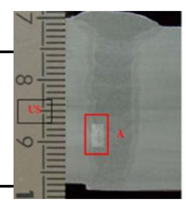
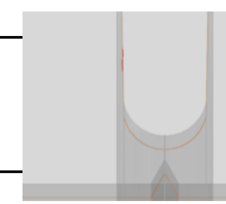
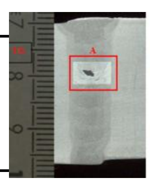
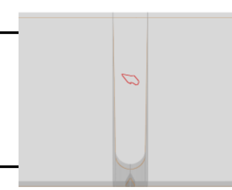
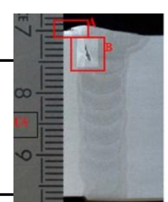
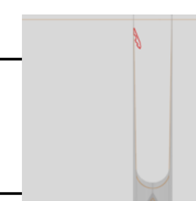
- Results: Comparison PipeWIZARD and CIVA charts
  - Reference reflector signal set at 80% FSH is framed in yellow



An overall good agreement

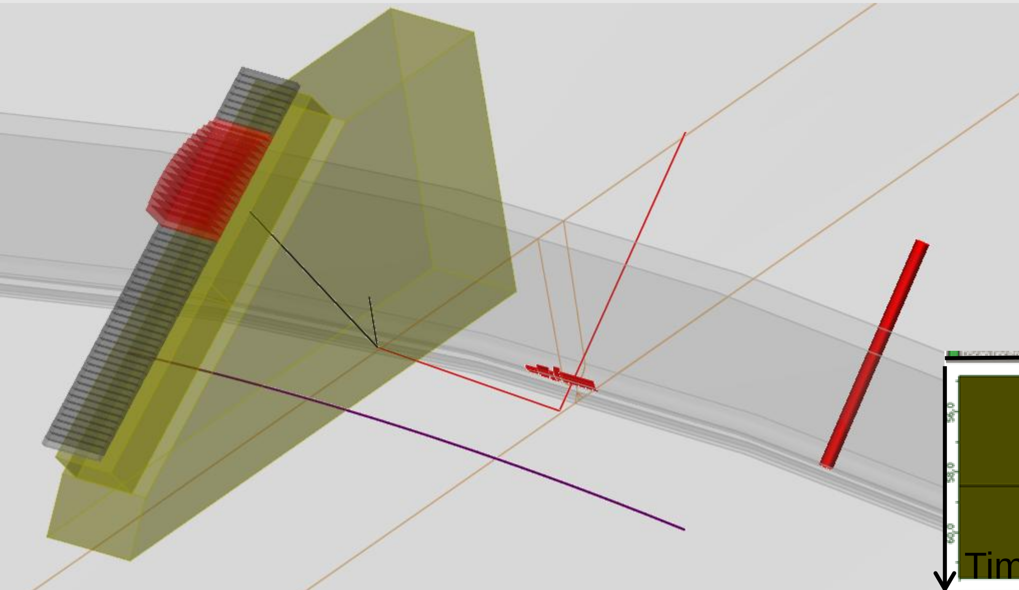
Modeling the qualification defective welds

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

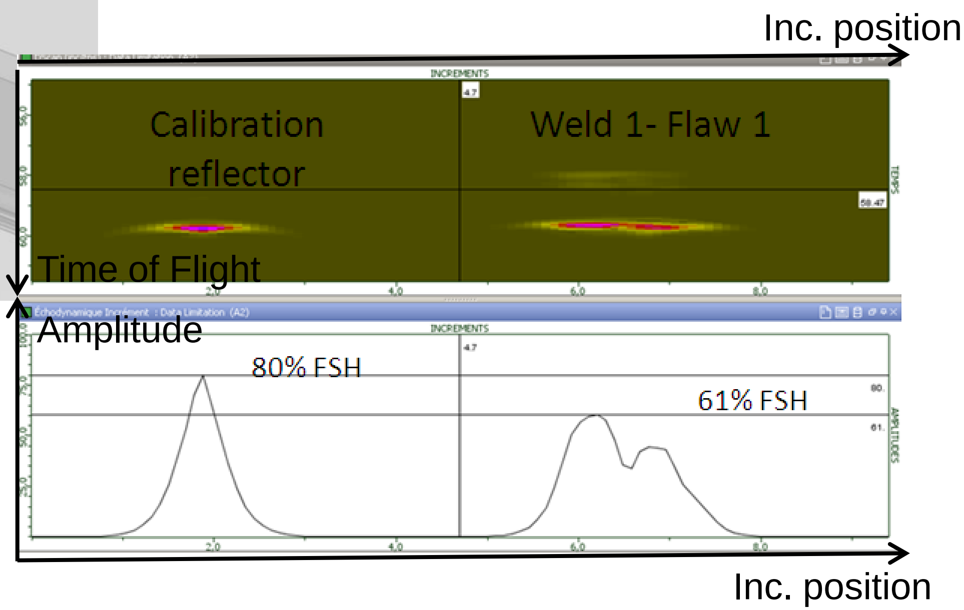
Type of Flaw	Salami cuts Macrograph(s)	View in CIVA
Weld1 – Flaw1: Lack Of Fusion 2.5mm	 Inc=1054mm  Inc=1055mm  Inc=1056mm  Inc=1057mm	
Weld1 – Flaw2: Burn Through 2.5mm	 Inc=2087mm  Inc=2090mm	
Weld2: Lack Of Fusion – 1.3mm	 	
Weld3: Porosity 3.5mm	 	
Weld4: Lack Of Fusion - 3 mm	 	

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:

Weld- Flaw	Channel	PipeWizard Result	CIVA Results	
Weld1 - Flaw1 (LoF)	F1U	73%	48%	
	H1U	58%	61%	
	R1U	SAT	SAT	
Weld1 - Flaw 2 (BT)	F1U	74%	10%	
	H1U	66%	57%	
	R1U	SAT	SAT	
	R2U	27%	SAT	
Weld2- Flaw 1 (LoF)	F1U	37%	45%	41%*
	F2U	24%	119%	28%*
Weld3 - Flaw 1 (Por)	V3U	SAT	SAT	
	V3D	27%	32%	
Weld4- Flaw 1 (LoF)	F7U	86%	90%	
	FC2U	75%	SAT	
	FC1U	SAT	SAT	

- 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

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Weld3 - Flaw 1 (Por)	V3U	SAT	SAT	
	V3D	27%	32%	
Weld4- Flaw 1 (LoF)	F7U	86%	90%	
	FC2U	75%	SAT	
	FC1U	SAT	SAT	

- 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)
- Weld 3-Flaw1: All channels OK
- Weld 4-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 ?