Code Compliant Ultrasonic Inspection with Enhanced PoD on Stainless Steel Welds using Phased Array

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Project Background

Agrium Inc. – V A U L T
VAnscoy ULTimate Expanse Project

In early 2013, Agrium requested PCL to explore the potential of PAUT in-Lieu of Radiography for Stainless Steel Piping Weld Inspection
Agrium Inc. – VAULT

VAntsoy ULTimate Expance Project

PCL recognizes Agrium’s Request

- As being a UNIQUE application
- Requiring Specialized Technical Knowledge
- Need for Extensive background in Advanced UT

PCL reviewed & analyzed Agrium’s request with three potential NDT Service Providers, by taking into account their

- Case History of Related Successful Projects
- Equipment Resources, and
- Number of Qualified Technicians

Selected Metalogic Inspection Services
The combination of coarse grain structure and anisotropy can significantly affect the propagation of ultrasonic waves, sometimes even to the extent that the ultrasonic waves are not able to penetrate the weld metal at all, or with great difficulty.
The following challenges may be encountered with varying degrees of difficulty, while ultrasonically examining an Austenitic Weld:

- Beam Distortion & Skew
- Attenuation and Scattering,
- Unexpected Reflection and Mode Conversion occurs on
  - Fusion Lines, and
  - Columnar Grains Boundaries

These difficulties may lead to:

- Undetected or Missed Flaws
- False Calls, and
- Unnecessary Repairs
The objective of this study is to:
- Reduce Production impacts caused by Industrial Radiography,
- Propose an Ultrasonic Configuration, which can
  - Provide full volumetric inspection coverage of weld zone
  - Be Consistent
  - Be Reliable & Repeatable

The Intent is to provide:
- Inspection results and Feedback, right at the end of welding, as compared to industrial radiography, where inspection is delayed till the end of the shift/day, which can be cost-prohibitive
Transducer Selection for Austenitic Stainless Steel Weld Inspection

For a reliable inspection of Austenitic Stainless Steel, and to reduce the problem of scattering, signal to noise ratio and interpretation issues emanating from mode converted received signals, following should be considered:

- Use of compression mode for volumetric inspection
- Use of Phased Array transducers for a highly directional and focused ultrasonic beam
- Use of Separate Transmit and Receive Sensors
All requirements (discussed previously) can be met, if a Transmit Receive Longitudinal Phased Array (TRL-PA) transducer is employed for Austenitic Weld Inspection.
Application & Inspection Configuration
Codes and Standard Requirements

- Method Application Standard
- Construction Acceptance Standard

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Application and Inspection Configuration

Configuration for Volumetric Inspection Coverage
Proposed Inspection Configuration is Employed
Reliable field inspection of Austenitic Stainless Steel Welds require:

- Calibration Samples representing field inspection
- Detailed Inspection Procedures
- Performance Qualification of Techniques

For a “Volumetric Inspection Coverage” and taking into account the limitations discussed earlier, PCL fabricated three (3) Stainless Steel Welding samples:
Calibration Sample ‘a’

- 10 mm Nominal Wall with 30° Weld Bevel
- Welding with GTAW using WPS # 8 – 8T1
Calibration Sample ‘b’

- 13 mm Nominal Wall with 30° Weld Bevel
- Welding Root with GTAW & Fills with SMAW using WPS # 8 – 8TA1
Calibration Sample ‘c’

- 13 mm Nominal Wall with 30° Weld Bevel
- Welding Root with GTAW & Fills with FCAW using WPS # 8 – 8MF4
Artificial reflectors are introduced and comprehensive inspection procedure developed by trying the conventional techniques (i.e. SW) first and progressing to special ones should they prove inadequate.

- 10% ID and OD EDM Notches are placed
- In 13mm Nominal Wall Samples (‘b’ and ‘c’) an additional OD Notch is placed by using a 3” cutting disk
- All caps are “ground flush” at designated notch locations
- Note:
  - The samples are ground flush to verify detectability during this study
Calibration, Inspection & Qualification
Application Test Results

Inspection Results

Ultrasonic inspection, using PAUT-SW, TRL-PA & Creep Waves is performed on welded samples. Inspection results presented in the following slides are grouped in three different categories:

⇒ ID Surface Reflectors
⇒ OD Surface Reflectors
⇒ OD Surface Cap-Center Reflectors
Application Testing Results – Calibration Results

ID Surface Reflectors

Phased Array Ultrasonic Testing using Shear Waves (PAUT – SW)

Near – Side

Far – Side

Calibration Sample ‘a’
Phased Array Ultrasonic Testing using Shear Waves (PAUT – SW)

Inspection Results
ID Surface Reflectors

Near – Side

Far – Side

Calibration Sample ‘b’
Phased Array Ultrasonic Testing using Shear Waves (PAUT – SW)

Inspection Results
ID Surface Reflectors

Calibration Sample ‘c’
Inspection Results
ID Surface Reflectors

Transmit Receive Longitudinal Wave Phased Array (TRL – PA)

Calibration Sample ‘a’

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Inspection Results
ID Surface Reflectors

Transmit Receive Longitudinal Wave Phased Array (TRL – PA)

Near – Side

Far – Side

ID NS Notch

Spurious or Metalurgical Signals

Calibration Sample ‘b’
Inspection Results
ID Surface Reflectors

Transmit Receive Longitudinal Wave Phased Array (TRL – PA)

Near – Side

Far – Side

Calibration Sample ‘c’
Inspection Results

OD Surface Reflectors

Phased Array Ultrasonic Testing using Shear Waves (PAUT – SW)

Near – Side

Far – Side

Calibration Sample ‘a’

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Inspection Results

OD Surface Reflectors

Phased Array Ultrasonic Testing using Shear Waves (PAUT – SW)

Near – Side

Far – Side

OD NS Notch

Spurious or Metalurgical Signals

OD FS Notch Not Detected

Calibration Sample ‘b’
Inspection Results
OD Surface Reflectors

Phased Array Ultrasonic Testing using Shear Waves (PAUT – SW)

Near – Side

OD NS Notch

Far – Side

OD FS Notch Not Detected

Calibration Sample ‘c’
Inspection Results
OD Surface Reflectors

Phased Array Creep Wave Inspection Scans

Near – Side

Far – Side

Calibration Sample ‘a’
Inspection Results
OD Surface Reflectors

Phased Array Creep Wave Inspection Scans

Near – Side

OD NS Notch
Sample ‘b’

Far – Side

OD FS Notch
Sample ‘b’

Calibration Sample ‘b’
Inspection Results
OD Surface Reflectors

Phased Array Creep Wave Inspection Scans

Near – Side

Far – Side

Calibration Sample ‘c’
Inspection Results
OD Surface Cap-Center Reflectors

Phased Array Ultrasonic Testing using Shear Waves (PAUT – SW)

90° Skew

270° Skew

Calibration Sample ‘b’
Inspection Results
OD Surface Cap-Center Reflectors

Phased Array Ultrasonic Testing using Shear Waves (PAUT – SW)

90° Skew

270° Skew

Spurious or Metallurgical Signals

OD Cap-Center Notch (90° Skew)

OD Cap-Center Notch (270° Skew)

Calibration Sample ‘c’

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Inspection Results

OD Surface Cap-Center Reflectors

Phased Array Creep Wave Inspection Scans

Sample ‘b’

Sample ‘c’

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ID Surface Notches (or ID Surface Reflectors)

- PAUT-SW setup is adequate to inspect Near-Side ID Notches with acceptable Signal-to-Noise Ratio
- Far-Side ID Notches are also visible, but not with an acceptable SNR, while employing PAUT-SW Setup. Their PoD is increased with the use of TRL-PA setup, and detected with acceptable SNR

Note:

⇒ Combined inspection configuration of PAUT-SW & TRL-PA is adequate for providing an acceptable & Code Compliant Inspection coverage for ID Notches (or ID Surface Reflectors)
Discussion on Inspection Results

**OD Surface Notches (or OD Surface Reflectors)**

- PAUT-SW setup is adequate to inspect Near-Side OD Notches with acceptable Signal-to-Noise Ratio (SNR)
- Far-Side OD Notches very difficult to inspect, and sometimes, they are not even detectable with PAUT
- With Creep-Wave setup, PoD for Far-Side OD Notches is increased and they become visible with acceptable SNR

**Note:**

- Combined inspection configuration of PAUT-SW & Creep Wave is adequate for providing an acceptable & Code Compliant Inspection coverage for OD Notches (or OD Surface Reflectors)
OD Surface Cap-Center Notches (or OD Surface Reflectors)

PAUT-SW setup is good for detecting these reflectors in TIG Welded Samples, as compared to ‘STT’ welded samples.

With Creep Wave setup, again the PoD is increased.

Note:

⇒ Combined inspection configuration of PAUT-SW & Creep Wave is adequate to provide an acceptable & Code Compliant Inspection coverage for OD Cap-Center Notches (or OD Surface Reflectors)
Procedure Demonstration and Qualification (PDQ)

- PCL specified the minimum acceptable technician qualifications & experience Levels that would be required, including:
  - Previous experience with PAUT of Stainless Steel Welds, and
  - An acceptable understanding of Data Acquisition Software with Data Auditing Expectations

Following the Application Testing & PoD results reviews:

- PCL conducted a Procedure Demonstration and Qualification (PDQ) with Metalogic’s resident Level-III Technician

Metalogic selected Level-II PAUT Technicians based on:

- PCL’s accepted qualification and experience requirements

On case-by-case basis, Metalogic provided additional application training to selected Level-II Techs prior to PDQ testing.
Code Compliant PAUT Inspection & Enhanced PoD for Stainless Steel
Procedure Demonstration & Qualification (PDQ)

Procedure Demonstration & Qualification Kit
Progress of Welding Project & Inspection

- Period for which the data is monitored and recorded
- Total Number of Welds Performed
  - 6531 Welds
- Total Number of Welds Inspected
  - Industrial Radiography (RT) 506
  - MetaPhase™ (PAUT) 374
- Total Number of Rejects with % Reject
  - Industrial Radiography (RT) 34 (6.72%)
  - MetaPhase™ (PAUT) 41 (10.96%)

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Comparison of Field Inspection Results

RT Inspection Results for Welding Program Duration
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Field Application
Comparison of Field Inspection Results

PAUT Inspection Results for Welding Program Duration

MetaPhase™ Field TRIaled (April 2013)
 MetaPhase™ Field Application Started (August 2013)

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The accumulative reject rate of PAUT is higher than RT. Over the full duration of the project (i.e. equivalent to x1.6)

From Aug. 2013, onward (Reject/Inspect)

- Radiography 28/358 (i.e. 7.82%), whereas
- MetaPhase™ (PAUT) 41/373 (i.e. 10.99%)

Note the Inspection (MetaPhase™ vs. RT) Ratio is 373 to 358, i.e. 104.2%
Field Application

Interaction with Welders

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Field Application
Comparison of Field Inspection Results

From Jun. 2014, onward (Reject/Inspect)
- Radiography 2/71 (i.e. 2.82%), whereas
- MetaPhase™ (PAUT) 11/223 (i.e. 4.93%)
- Note the Inspection (MetaPhase™ vs. RT) Ratio is
  223 to 71, i.e. 314.08%

For Last 6-months (Reject/Inspect)
- Radiography 1/5 (i.e. 20.00%), whereas
- MetaPhase™ (PAUT) 11/223 (i.e. 4.93%)
Conclusions

- Ultrasonic Shear Wave Inspection, has limitations for Austenitic Stainless Steel Weld Inspection
- Use of PAUT-SW only, cannot provide the volumetric coverage for Austenitic Stainless Steel Weld Inspection
- Near-Side inspection of Full Fusion Boundary is possible and provide users with acceptable SNR
- TRL-PA Sensor, because of their ‘discussed’ advantages, can be used to inspect the Weld Volume in the 1st Leg of Ultrasonic Soundpath.

⇒ AND DUE TO LIMITATIONS ON CAP REMOVAL. THE 1ST LEG WAS LIMITED TO ID SURFACE DETECTION
Conclusions

Remaining, “top weld volume” can now be inspected using creep waves

Proposed Inspection Configuration, using multiple UT Techniques, will provide full inspection coverage in-line with code requirements (i.e. ASME B31.3)

Field Application
- Proper application of “proposed configuration” is IMPORTANT
- In the long run, if properly applied, will IMPROVE process and SAVE COSTS

The Impact of MetaPhase™ (PAUT)
- Increase in “Rate of Inspection” (i.e. ↑ up to 314 %)
- Decrease in “Rate of Reject” (i.e. ↓ down to 4.93 %)

Due to actual site application thicknesses, PAUT was the primary technique
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QUESTIONS ???