Total Focusing Method (TFM) for Automated Pipeline Girth Weld Inspections

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Context

• Inspection of girth welds is crucial in the oil & gas industry
• Weld defects can be tragic for companies and the environment
• Each weld is inspected during new construction
• Automatic Ultrasonic Testing (AUT) is a quite common NDT method and included in standards (ASTM, API, DNV...)

Recent Girth Weld Incidents
Objective

- Evaluate the Total Focusing Method (TFM) for girth weld inspection
- Obtain flaw sizing results with TFM (flaw, depth and height)
  - The TFM imaging algorithm will be applied to data acquired with the Full Matrix Capture (FMC) technique
- Comparison with (P)AUT and destructive testing (Macrography)
- Practical considerations: Scan speed, etc.
Inspected Parts

- **Carbon Steel Pipes**
- **Diameter**: Ø24in/610 mm
- **Thickness**: 0.75in/19.1 mm
- **Longitudinal Velocity**: 5910 m/s
- **Transversal Velocity**: 3220 m/s
• **2 Phased array probes**: 60 elements, 1mm Pitch, 7.5 MHz
  • One probe on either side of the weld
• **Wedge angle** = 33.7°
• Shear waves used for defect detection
• Circumferential scanner
PAUT Instrument AOS OEM–PA 128/128

• **Super Fast Data Rate!**
  – 160 MB/s (for high frame rate)

• **Full-Matrix Capture (FMC)**

• **Total Focusing Method (TFM) (5 Different Styles):**
  – Standard TFM
  – Migration TFM
  – Advanced TFM
  – Adaptive TFM
  – TFMp

• **Utilizes GPU**
  – For faster TFM calculation speed

• **Open!**
  – Access raw data and low level parameters
Wave Modes: Pulse/Echo

Multiple Wave Modes can be processed in parallel with one FMC acquisition!
Wave Modes: Pitch/Catch

TT

LL

T-TT

L-LL

TT-TT

LL-LL

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Zonal Discrimination

*Drawing from ASTM E1961-11
Zonal Discrimination

Phased Array Probe 4

Phased Array Probe 1

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TFM Benefits vs. Zonal Discrimination

- Any zone of the weld can be imaged, so misalignment of the probe in reference to the weld will not affect scan results.

- The TFM resolution can be defined arbitrarily. In this case, 0.1mm was chosen which provided a good compromise between image resolution and reconstruction complexity.

- Since we have the full data set, we can obtain complimentary views.

- All views are done with one (FMC) data capture.

- With all views, a 6dB drop sizing function can be applied volumetrically (in 3D).

- The data can be reprocessed at any time with a change of parameters. Examples are material velocity and wave modes like TT, LL, TTT...etc.
• Upstream Side – Pulse/Echo
DNV Cal Block: Fusion Line
DNV F.L. Cal Block: TFM Results

• Upstream Side – Pulse/Echo
Lack of Fusion Flaws

Lack of Fusion

Lack of Fusion
TFM Results C1: XZ View (B-Scan)

Theoretical weld bevel

Lack of Fusion
TFM Results C1 : XY View (C–Scan)

Lack of Fusion

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TFM Results C1: YZ View (D-Scan)

Side view

Lack of Fusion
Flaw Sizing from XZ view (B-Scan)

TFM Automated Sizing Results
Macrography results of the First Coupon

Lack of Fusion flaws
## Macrography Results (First Coupon)

<table>
<thead>
<tr>
<th>Value</th>
<th>Macrography</th>
<th>AUT</th>
<th>TFM (TTTT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth (mm)</td>
<td>15.60</td>
<td>17.0</td>
<td>15.60</td>
</tr>
<tr>
<td>Height (mm)</td>
<td>1.30</td>
<td>1.6</td>
<td>1.24</td>
</tr>
<tr>
<td>Error in height (%)</td>
<td>-</td>
<td>23.1</td>
<td>4.6</td>
</tr>
</tbody>
</table>

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Macrography (Second Coupon)

Lack of Fusion (Root Area) with misalignment
Lack of Fusion (Root Area)
TFM Results C2: XY View (C-Scan)

Lack of Fusion (Root Area)

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TFM Results C2: XZ View (B-Scan)

Root Edge
TFM Results C2: YZ View (D-Scan)

Lack of Fusion (Root Area)
Flaw Sizing from XZ view (B-Scan)

TFM Automated Sizing Results

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## Macrography Results (Second Coupon)

![Macrography Images](image)

<table>
<thead>
<tr>
<th>Value</th>
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<th>AUT</th>
<th>TFM (TTTT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth (mm)</td>
<td>root</td>
<td>19.1</td>
<td>18.10</td>
</tr>
<tr>
<td>Height (mm)</td>
<td>0.45</td>
<td>2.2</td>
<td>0.77</td>
</tr>
<tr>
<td>Error in height (%)</td>
<td>-</td>
<td>388.9</td>
<td>71.1</td>
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</tbody>
</table>
# Flaw Sizing Results Comparison

## Lack of Fusion (Volumetric):

<table>
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<tbody>
<tr>
<td>Depth (mm)</td>
<td>15.60</td>
<td>17.0</td>
<td>15.60</td>
</tr>
<tr>
<td>Height (mm)</td>
<td>1.30</td>
<td>1.6</td>
<td>1.24</td>
</tr>
<tr>
<td>Error in height (%)</td>
<td>-</td>
<td>23.1</td>
<td>4.6</td>
</tr>
</tbody>
</table>

## Lack of Fusion (Root):

<table>
<thead>
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<th>Macrography</th>
<th>AUT</th>
<th>TFM (TTTT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth (mm)</td>
<td>root</td>
<td>19.1</td>
<td>18.08</td>
</tr>
<tr>
<td>Height (mm)</td>
<td>0.45</td>
<td>2.2</td>
<td>0.78</td>
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<tr>
<td>Error in height (%)</td>
<td>-</td>
<td>388.9</td>
<td>73.3</td>
</tr>
</tbody>
</table>

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Next Step FMC/TFM

- FMC/TFM Results with Long Seam

- Advantages
  - Easy flaw location
  - Multiple Wave Mode analysis & 3D display: easy flaw characterization
  - More reliable data analysis
Summary of Results

- 4 Girth welds were tested with FMC/TFM
- 27 Imaged defects from US and DS
- TFM provided superior flaw height accuracy over AUT
- Flaw detection efficiency was achieved by TFM due to its ability to produce multimodal imaging
- Sizing can be achieved volumetrically/in 3D
- Overall, the results of sizing from TFM proved more precise than with conventional AUT
• Based on the results achieved with this study, industry would benefit greatly from implementing an automated FMC/TFM inspection procedure for girth weld inspections.