Volumetric Inspection of Welds Using the Total Focus Method

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Agenda

• Background
  • Inspection task
  • Inspection system
• MIT Approach to Inspection
• Derivation, additional considerations & error sources
• Results of experiments
Background - Inspection Task
Background - Inspection Task
Background - MIT Inspection System

Matrix Inspection Technique
= Full Matrix Capture data acquisition + Total Focus Method data analysis
Background - MIT Results

Individual weld cross sections assembled into 3D representation
Inclusion in Weld

Could TFM beam forming be extended to image discontinuities in the weld volume?

Weld inclusion identified in multiple adjacent frames
Objective

• Provide full volumetric inspection capability for arbitrary weld geometry
  1) Exterior surface breaking
  2) Isolated internal discontinuities
  3) ID surface breaking

• Subset: image ID breaking indications
Full Matrix Capture

- Generates $n^2$ matrix of A scans
- Represents maximum amount of data collected (very large data files)
- All other techniques derived from FMC
- Fundamental constraint – ability to get sound into and back from inspection volume
- Well suited to automated analysis methods
Derivation

\[ t_{i,j} = \sum_{B,E \in S_E, \ C \in S_I} \frac{\overrightarrow{AB}}{V_l} + \frac{\overrightarrow{BC}}{V_{Sm}} + \frac{\overrightarrow{CD}}{V_{Sm}} + \frac{\overrightarrow{DE}}{V_{Sm}} + \frac{\overrightarrow{EF}}{V_l} \]

\[ I_D = \sum_{i,j} U(T_{i,j}) \]
Mode Combinations – Single Skip

- Single skip creates 8 possible mode combinations, two skips create 16 mode combinations
- Computational burden – Is it worth it?
- Application specific

<table>
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<tr>
<th>Leg</th>
<th>Mode</th>
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<tr>
<td>$\overrightarrow{BC}$</td>
<td>L  L  L  L  S  S  S  S  S  S  S  S</td>
</tr>
<tr>
<td>$\overrightarrow{CD}$</td>
<td>L  S  L  S  L  S  L  S</td>
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<tr>
<td>$\overrightarrow{DE}$</td>
<td>L  L  S  S  L  L  L  S  S</td>
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Additional Considerations

- Dynamic range of signals
- Signal suppression
- Phase inversion of reflected signals
- Mode conversions – phase error
- Parameter errors
- Conditional summation
FMC data set – 5 mm x 1 mm EDM notch
Dynamic Range

- Interface ~ 100% FSH - Reference
- L-wave tip diffraction: 1.4% FSH ~ -37 dB
- Interior L-wave reflection: 8.2% FSH ~ -22 dB
- L-wave corner trap: 1.9% FSH ~ -34 dB
- Mode Conv. Corner trap: 2.8% FSH ~ -31 dB
- S-wave corner trap: 8.7% FSH ~ -21 dB

Note: Water TCG curve active
Signal Suppression

8 mm EDM notch - 25 mm CS Block

L-L, no suppression
L-L, L-L-L, no suppression
All modes, suppression
Phase Inversion & Mode Conversion

- Phase inversion – reflection at low impedance interfaces - cancellation of intended signals
- Solution – monitor number of reflections – invert signals as necessary
- Mode conversion – phase error ppl flight time in mode
- Possible solution – frequency domain processing
Phase Inversion - cancellation

Phase Inversion not accounted for

Phase Inversion accounted for
Error Sources

- L-Wave velocity \(< 0.4\%\>
- S-Wave velocity \(< 0.3\%\>
- Exterior surface coordinates \(< 0.02 \text{ mm}\>
- Interior surface coordinates \(< 0.05 \text{ mm}\>
- Couplant velocity \(\text{?}\)
- Transducer element delays \(\text{?}\)
Conditional Summation

Combined – note cancellation effect

Contributions from elements on right side

Contributions from elements on left side
Example - 1 mm Notch in 5 mm block

Conditional summation vs Correlation
Example - 1 mm EDM Notch in 5 mm block

Images formed separately then combined (logical operators)
Example - 1 mm EDM Notch, 6 mm Step

Original image

Composite image with EDM notch
Examples - HAZ Crack

- 1 mm HAZ crack imaged adjacent weld
Examples - Crack with Excess Root Pen.

- Crack and excess penetration imaged at weld root near intrados of bend
- Improvement in ID coordinate accuracy would yield better imaging
Conclusions

• Ability to image surface breaking discontinuities using TFM beam forming has been demonstrated
• EDM notches in blocks, implanted flaws in weld samples
• Additional complicating factors must be taken into account
• Errors can accumulate rapidly – accuracy is key to successful imaging
The End

Thank –you

Questions?