Guided Wave in Engineering Structures
Using Non-Contact Electromagnetic Acoustic Transducers – A Numerical Approach for the Technique Optimisation.

Dr. Slim SOUA
What is TWI?

World Centre for Materials Joining Technology and allied Technologies

- Membership based Research and Technology Organisation since 1946
- Company limited by guarantee
- 580 staff worldwide
- £38m turnover in 2006
- Over 3500 Industrial members in 60 countries
- Non profit distributing
• Provides Teletest Services and Equipment
  – Long Range Ultrasonic Testing using Guided Waves (GW)
• Wholly owned subsidiary of TWI
• Corrosion of insulated pipe is a problem
• Many areas are inaccessible
• Costs of access exceeds costs of inspection
• 70% of plant inspection cost relates to pipework
Guided waves offers:

- Rapid screening for in-service degradation,
- Reduction in costs of gaining access
- Avoidance of removal/reinstatement of insulation or coating, except at location of transducer tool
- Ability to inspect inaccessible areas
  - i.e clamps and cased or buried pipes
- 100% coverage
Conventional UT versus LRUT

Conventional Transducer

Localised Inspection

Weld

Metal loss

Metal loss

Guided wave transducers

Guided Wave

100% Inspection

Weld

Metal loss

Metal loss

Flange

Flange
Features

- **Diameters** – 1.5” to 48"
- **100% Coverage**
- **Test Range**
  - Typical ±30m
  - Ideal conditions ±180m
- **Productivity**
  - Typical 500m per day
  - Under ideal conditions 3km has been achieved
- **Service Temperature up to** +125°C
- Detection of internal or external metal loss
- Sensitivity
  - Metal loss down to 3% of pipe wall cross-section
  - Reliable detection of 9% metal loss flaws
- Discrimination between flaws and pipe features; welds, bends, supports, etc.
- Longitudinal accuracy better than ±100mm
• Road and river crossings
• Power plant tubing
• Risers
• Offshore topsides pipework
• Jetty lines
• Chemical plant pipework
• Tank farm link lines
• Sphere legs
• Pipe bridges
• Spiral welded pipe
• Refinery pipework
Examples of Application

Road Crossings

Sphere Support Leg

Buried Pipe

Gas Pipelines
Key Features

- Easy to use unit and tool design for quick data collection
- Multimode – Longitudinal and torsional wavemodes on one tool
- Focusing – Defect distribution around circumference “one-click” away
- User friendly interface with report manager generator
Collar design

- Robust composite construction
- Integrated clamp and bladder
- Collars link for >24” up to 48”
- Multimode
- Lightweight
- Cost efficient
• Automated set-up
• Fast and reliable defect detection
• Multimode
• Simplified Analysis
• On-site MS Word report generator
• <15 min data collection time/location
Modelling using COMSOL

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Overcome limitations of using PZT surface contact sensors.

Require mechanical coupling usually achieved using:

(i) immersing method (transfer of the ultrasonic signals between the transducer and test sample by placing both objects in liquids).

(ii) contact (the transducer is pressed directly against the test sample with or without coupling gel).

Inspection of very high temperature pipelines and tubes above 500°C, both coupling methods are extremely problematic.
1. Determine a set of parameters for the testing:
   Dispersion curves
   • GW mode selection
     • Frequency
     • Wavelength
     • Excitation

2. Transient analysis:
   Verify the A scan content
   • Optimise the NCET configuration
     • Spacing
     • Mode spectra amplitude
GW form in frequency domain: \( U(x,y,z,t)= A(x,y) \exp(j\xi z) \exp(j\omega t) \)

\[ \lambda = \frac{L}{n}, \text{ where } L \text{ is the length of the pipe (} L = 40\text{mm)} \]

\[ C = \lambda f \]
<table>
<thead>
<tr>
<th></th>
<th>L(0,3)</th>
<th>Inner Surface</th>
<th>Outer Surface</th>
<th>Inner Surface</th>
<th>Outer Surface</th>
<th>Inner Surface</th>
<th>Outer Surface</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>f (Hz)</em></td>
<td>402,476</td>
<td>448,270</td>
<td>492,446</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>L(0,4)</td>
<td>Inner Surface</td>
<td>Outer Surface</td>
<td>Inner Surface</td>
<td>Outer Surface</td>
<td>Inner Surface</td>
<td>Outer Surface</td>
</tr>
<tr>
<td><em>f (Hz)</em></td>
<td>426,475</td>
<td>431,332</td>
<td>490,140</td>
<td></td>
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Mode shape of the L(0,3) and L(0,4) GUW
Correlation of the COMSOL dispersion curves results with analytical solution.

Point of minimum dispersion of L(0,3) (441kHz, 459m⁻¹) \( \lambda_{L03} = 13.6 \text{mm} \)
Transient analysis

Schematic of the current, magnetic field and the Lorentz force, generated in tubular structure.

Frequency spectra of the $N$ cycles tone burst excitation.

$I = I_0 \sin(\omega t) \left(1 - \cos\left(\frac{\omega t}{N}\right)\right) \text{ for } t < N/f$

Three axisymmetrical formulations:

1/ Static field induced by a permanent magnet.
2/ Induced magnetic field pulsed from the coils.
3/ Elastodynamic wave travelling in the pipe induced by the Lorentz forces.
Conf. 1: Full magnet without spacing
Conf. 2: Series of 7 magnets with $\lambda L_{03}$ spacing
Conf. 3: Series of 14 magnets with $\lambda L_{03}$ spacing

2DFFT amplitude of the modes for various NCET configurations.
## Summary of modes maximum amplitudes

<table>
<thead>
<tr>
<th>Conf.</th>
<th>Maximum Amplitude</th>
<th>1</th>
<th>2</th>
<th>3</th>
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<tbody>
<tr>
<td>L(0,1)</td>
<td>0.2</td>
<td>1.1</td>
<td>+0.9</td>
<td>2.5</td>
</tr>
<tr>
<td>L(0,2)</td>
<td>0.4</td>
<td>2.3</td>
<td>+1.9</td>
<td>2.7</td>
</tr>
<tr>
<td>L(0,3)</td>
<td>0.5</td>
<td>4</td>
<td>+3.5</td>
<td>5</td>
</tr>
<tr>
<td>L(0,4)</td>
<td>0.3</td>
<td>1</td>
<td>+0.7</td>
<td>0.6</td>
</tr>
<tr>
<td>L(0,5)</td>
<td>0.23</td>
<td>0.3</td>
<td>+0.07</td>
<td>0.1</td>
</tr>
</tbody>
</table>
Conclusions

COMSOL: used to develop, optimise and select the GW for LRUT.

• Multiphysic interaction: a concept for modelling the excitation of GW using non-contact transducers.
• Optimisation of the experimental conditions.

Future work:

• 3D modelling: NCET divided in n modules (memory issue)
• Correlation
• Experimental