The Guided Wave Testing Method for Screening of Pipelines

V Pan American Conference for Non Destructive Testing
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Outline

- Introduction to guided waves
- Concept of guided waves for NDT
- Development of guided wave modelling tools
- Properties of guided waves
- Development of GWT for pipelines
- GWT of pipelines in practice
- Future directions
Sound waves

Pressure = A \cdot e^{i(kx - \omega t)}
Conventional ultrasound NDT

Pulse-echo test

"Flaw detector" for pulse-echo test
Conventional ultrasound NDT

Ultrasound imaging

But what about "guided waves?"
But what about guided waves?

Tin Can Cellular: Test Commercial

Could guided waves be useful for NDT?
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### Concept of long range guided wave inspection

- If the guided wave encounters a defect then part of the signal is reflected
- A single measurement inspects all the material in a long length of the structure
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What happens if we just try......

Problems:
- Multiple modes
- Dispersion
- Sensitivity to defects varies with modes

Guided wave dispersion curves

"Dispersion curves" for a 1mm thick steel plate

L Rayleigh (1885); H Lamb (1917)
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Development of the waveguide model

DISPERSE

Field in layer of material is built up by summation of partial waves
....including multiples if waveguide has multiple layers

Boundary conditions must be satisfied at all interfaces:

(1) Between the layers
(2) At the top and bottom surfaces

(2a) If the plate is in vacuum:
(2b) If the plate is immersed:
This results in a Characteristic Function:

For a Plate or Cylinder in Vacuum:
\[ f(\omega, k_{\text{real}}) = 0 \]

For a Plate or Cylinder Immersed or Embedded:
\[ f(\omega, k_{\text{real}}, k_{\text{imag}}) = 0 \]

The Dispersion Curves are the Solutions of the Characteristic Function. These are lines in 2D or 3D space.
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......and also:

- Solids, fluids, anisotropic....
- Bars
- Pipes
- Multiple layers
- Embedded or immersed

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DISPERSE software:

- First version 1991
- MS Windows versions since 1997
- Widely used for guided wave research
- More than 80 licensed clients

Development of Finite Element Modelling Tools

Finite Element simulation to calculate reflections from defects

Scattering of guided waves from a crack

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Phase and group speed
Phase and group speed example: wake from boat

Expected          Actual

Group speed = 0.5 phase speed
Phase and group speeds
Dispersion curves for a 1mm thick steel plate

Effect of dispersion after long distance of travel
Leaky waves
Dispersion curves for a 1mm thick steel plate in water

Mode shapes

Mode shapes are the key to understanding wave behaviour at defects and features
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UK Research Centre in Non Destructive Evaluation (RCNDE)

- Founded in 2003
- Research collaboration between UK universities and industry
- 6 Universities, including Imperial
- 17 major industrial companies
- Director: Professor Keith Newton
Guided Ultrasonics Ltd (GUL)

- Founded in 1999
- Spin-out company from the NDT group at Imperial College
- The world leader for exploitation of guided waves
- Develop and manufacture equipment
- Training and support in use of guided waves for NDT
- Chairman: Malcolm Russell

Guided wave Testing (GWT) of pipelines
Need to find corrosion.....
Concept of long range guided wave inspection:

Need to do a lot of R&D, including:

...then develop transducers, instrumentation, controlling software, signal processing, interpretation, operator training, formal procedures.....etc
Brief history of the development of GWT for pipes

- Started at Imperial College: 1987
- Understanding of guided wave properties: 1992
- Understanding of guided wave reflections from simple defects: 1995
- Development of transducers and signal processing: 1997
- Commercialisation (licensed by Imperial College): 1997
- Procedures formalised in published standards: 2009

Strategy for development of Guided Wave Testing

- Find a guided wave mode which is sensitive to defects at any location in the pipe wall
- Select frequency and signal shape to minimise dispersion
- Excite and receive ONE mode in ONE direction
Dispersion Curves for 6 Inch (150mm) Pipe

Mode shapes: torsional modes family

T(0,1)  F(1,2)
Need to understand the sensitivity of the modes to defects

Finite Element simulation of reflections from defects
Reflection coefficient versus circumferential length of defect

![Graph showing reflection coefficient versus circumferential length of defect with curves for T(0,1), F(1,2), and F(2,2).]


Similar study done for extensional modes.

Reflection coefficient versus depth of defect

![Graph showing reflection coefficient versus depth of defect with curves for defect depth (% of thickness) and frequency (kHz) for a 6 inch pipe.]


Similar study done for extensional modes.
Sensitivity experiments using machined “defects”

Need to develop transducers:
- One mode
- One direction
Development of a non-resonant low frequency transducer


Early Research Transducers
Transducers in commercial use (Guided Ultrasonics Ltd)

Flexible transducer band used for large diameter pipes
Summary of GWT research topics

- **Guided wave theory**

- **Transduction**

- **Reflection sensitivity**

- **Butt welds**

- **Bends**

- **Supports**

- **Flanges, tees, valves**

- **Coatings**

- **Surrounding materials when buried**

- **Improved interpretation**
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Example of practical use of the guided wave inspection method: testing of refinery pipeline at road crossing

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Measured signals shown in the form of an "A-Scan"

Results show corrosion at entrance to road crossing

Symmetric (black) and flexural (red) signals are used for interpretation

Measured signals shown in the form of a "C-Scan"
(Unrolled pipe view)

(Note: this is different example than previous slide)
Examples of GWT in practice

Here’s an easy location for testing....
But it can be much less comfortable! (testing in Alaska)

Testing offshore
What is the role of GWT in NDT?
The role of GWT of pipelines:

SCREENING

- GWT is used to identify (call) indications at locations of possible concern.
- Conventional methods of NDT are used locally at the locations of concern to evaluate indications.

Sequence 1:
Perform the GWT
Sequence 2:
Analyse the signals to identify indications

Sequence 3:
Follow up using conventional NDT methods
Recommendation:

Presentation at 12.30, in room Xcaret 1

"Guided Wave Testing of an Immersed Gas Pipeline"

Victor Nuñez

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Future directions A:
Characterisation of defects in inaccessible places

Buried pipes
Under saddle supports

Extended interpretation of GWT signals to find more information about indications
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Tomographic imaging using transmission signals

Future directions B:
Permanently Installed Monitoring System (PIMS)

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Conclusions

- Guided waves can provide a lot of information but they are very complicated.
- Exploitation has been made possible through careful research of the fundamental physics, and development of specific instrumentation.
- GWT has been commercialised and is now well established in industrial use.
- GWT procedures and certification of GWT personnel are now implemented in published standards.

Guided Wave Mini-Course
14:30 – 18:00  XCARET 1

- Introduction to Guided Wave basics
- Target applications and limitation
- Case studies
- Training

- Course for engineers and managers
- Final users and service companies

- You can book at registration desk, limited space available.
Thank you!