NEW MODELS FOR ULTRASONIC GUIDED WAVE INSPECTIONS IN CIVA

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Presentation of CIVA GW

Simulations based on hybrid SAFE-FE method

- Theory
- Simulation of a complex junction
- Simulation of corrosion pitting in an aluminium plate

Mode and wave-field computations in guides of arbitrary sections

- Theory
- Modal and wave-field computation in a rail
PRESENTATION OF CIVA GW
CIVA: SOFTWARE FOR NDT

WHY USING SIMULATION IN NDT?
- Design of new methods and probes (e.g. phased arrays)
- Qualification of methods, performance demonstration
- Interpretation of complex results, diagnosis
- « Virtual testing » in product design phases
- Training

CIVA: SIMULATION FOR NDT
- Multi-technique platform: UT, ET, RT-CT… Guided Waves
- Experimental validation within international benchmarks

ET : 2D map of a complex defect
RT : weld inspection
CT : tomographic reconstruction of complex parts
FIRST RELEASE : May 2012

Specimens
- plates (2D computation: Lamb/SH wave)
- pipes/cylinders (2D and 3D computation)
- multilayered (no immersed or embedded guides)

Materials
- isotropic solid
- attenuation law: linear with frequency

Transducers
- contact with or without wedge
- encircling/encircled probes (phased arrays)
- different type of solicitations
- pulse-echo/pitch-catch configurations

Flaws
- cracks orthogonal to the guide axis
Steel pipe with viscoelastic coating
• outer diameter: 115mm
• pipe thickness: 6mm
• coating thickness: 0.5mm

Displacement profile for arbitrary mode
FIELD COMPUTATION (APPLICATIONS: MODE SELECTION, DESIGN OF SENSORS)

- Visualization of displacement/stress field emitted by a transducer
- Display of the modal amplitude generated by the transducer

Civa simulation

Experimental measurement by Terrien

Configuration

DEFECT RESPONSE

• Display of Ascan
• Display of the modal amplitude diffracted by the defect

Steel pipe
• outer diameter: 88.7 mm
• pipe thickness: 5.5 mm
• Fc ~ 100 kHz

Tang Li-Guo, Mechanism of the excitation of single pure mode \(L(0,2)\) and its interaction with the defect in a hollow cylinder, *Chinese Physics*, 2007
FEATURES OF CIVA 11 GW

SECOND RELEASE : expected in November 2013

- Hybrid modal/FE modelling for 2D and axisymmetric configurations
  
- Mode and field computation in guides of arbitrary section
  
- New simulation possibilities for pipe inspections
  - account of inner fluid
  - computation of delay laws
SIMULATIONS BASED ON HYBRID SAFE-FE METHOD
HYBRID FE/MODAL METHOD – TRANSPARENT BOUNDARY CONDITIONS

(V. Baronian, PhD – 2009)

× Radiation conditions at $\infty$
  are brought back to the artificial boundaries (TBC)

× No spurious reflection!

Using scattering matrix formalism

NTD experiment
Interaction of GW with defect

Scattering Matrix Formalism (Modal)

$\partial \Omega_d = \Sigma^+ + \Sigma^- + \Gamma$

$S = \begin{pmatrix} R_{11} & T_{12} \\ T_{21} & R_{22} \end{pmatrix}$

$\Psi^{\text{out}} = S\Psi^{\text{in}}$

$\Psi^{\text{out}} = \begin{pmatrix} B_1 \\ A_2 \end{pmatrix} \quad \Psi^{\text{in}} = \begin{pmatrix} A_1 \\ B_2 \end{pmatrix}$
- 50mm-thick plate
- Wedge transducers (31°) in pitch-catch configuration
- \( f_c \approx 110 \text{ kHz} \) [6 propagating modes]

**FE Mesh**
- ~ 7000 elements
- ~ 14000 nodes

*Distribution of energy in the emitting branch as a function of frequency*
Snapshots of displacement wave-field inside the junction at $t=350\mu s$ (a), $t=385\mu s$ (b), $t=420\mu s$ (c), $t=455\mu s$ (d), $t=490\mu s$ (e) and $t=525\mu s$ (f)
SIMULATION OF RECEIVED SIGNAL

Ascan

Emitter      Receiver

Receiver      Emitter

-13 dB

Received modes

S0

A0, A1

S0, S1
Use of Lamb modes at relatively high frequency to detect corrosion

- 2mm thick aluminium plate
- Wedge transducers (angle adjusted to emit S0)
- $f_c \sim 2\text{ Mhz}$ [5 propagating modes]

Corrosion pits modelled by a distribution of 100µm depth and width notches

Distribution of emitted energy among propagating modes (%)

![Diagram showing energy emission-GW Modes vs Frequency with labels S0, A0, A1, S1, S2.](image-url)
INFLUENCE OF CORROSION LENGTH

Distribution of transmitted energy towards the receiver among propagating modes (%) as function of corrosion length

L=0
L=2mm
L=5mm
L=10mm

Relative amplitude of received signal:
0dB
-0.5dB
-3dB
-4dB

Conclusion: SO to A0 mode conversion increases with corrosion length
Corrosion pitting vs plate thinning

**Corrosion pitting**

- No mode conversion for 100µm deep corrosion pitting

**Plate thinning**

- S0 to A0 conversion for 100µm deep plate thinning

Good agreement with experimental and numerical conclusions of Terrien et al.

N. Terrien et al., Numerical predictions and experiments for optimizing hidden corrosion detection in aircraft structures using Lamb modes, Ultrasonics, 2007
MODE AND WAVE-FIELD COMPUTATIONS IN GUIDES OF ARBITRARY SECTIONS
Semi Analytical Finite Element Method


used to model straight guides of arbitrary section
account of anisotropy, viscoelasticity, multi-layered structures

- Meshing of only the section by finite elements:

- Resolution of a quadratic eigensystem (3Mx3M with M number of nodes)

\[(K_1 + j\beta K_2 + \beta^2 K_3)d - \omega^2 Md = 0\]

Wavenumbers  Displacement
FE mesh
6 node triangular elements

Modal displacement and stress (arbitrary mode)

Dispersion curves: phase & group velocity (0-100kHz)
- piezo emitter
- fc ~ 40kHz
CONCLUSION AND PERSPECTIVES
Models soon available in CIVA platform for GW
- Account of 2D CAD waveguides (rail)
- Hybrid modal/FE computation for 2D and axisymmetric case
- New simulation possibilities for pipe inspections
  - account of inner fluid
  - computation of delay laws

Current and future developments
- Hybrid modal/FE computation for 3D case
- Anisotropic materials
- Generation by EMAT (coupling with ET module)