A Simulation Platform for Structural Health Monitoring: CIVA SHM

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Outline

- Introduction to EXTENDE & CIVA Platform
- Benefits of simulation for SHM
- Validation and application of CIVA SHM
EXTENDE activities

World wide CIVA DISTRIBUTION and technical SUPPORT

TRAINING COURSES:
CIVA, « Reliability in NDE »

CONSULTING: qualifications, design, expert assessment, computations, …

TraiNDE: Virtual training tool for NDE operators

European NDT & CM 2021
Prague, Czech Republic
October 4-7, 2021

ISO 9001
CERTIFIED

FQA4003807
CIVA in a few words

- Software platform **dedicated** to NDE & SHM simulation & analysis

- Multi-technique **Simulation**:
  - **UT**: Ultrasounds
  - **RT-CT**: Radiography (X-rays & Gamma Rays) & Computed Tomography
  - **ET**: Eddy Current
  - **GWT**: Guided Waves
  - **SHM-GWT**: Structural Health Monitoring by Guided Waves
  - **TT**: Thermography Testing
  - « CIVA Script » option available

- Developed by R&D Center: **CEA LIST**

- Exclusive Distribution: **EXTENDE**

- **UT Data Analysis**

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CIVA SHM by Guided Waves includes:

- Dispersion curves computation tool:
- Inspection Simulation tool:
  - Simulations of all sensors signals with/without defect(s)
  - Reconstruction imaging on 3D view
  - Local displacement/stress fields extraction

Covers:

- Metallic and composite plates with potential curvatures and stiffeners
- Metallic pipes
- Defects: Holes, Cracks, Delamination, Erosion
Simulation for SHM

Structural Health Monitoring still suffers from a lack of industrial deployment. Why?

Some reasons: High cost?

- Needs to optimize the monitoring setup to find the best compromise “Cost” vs “Number of sensors” vs “Detection performance”
- Virtual prototyping shall help to:
  - Try and select some sensors (Size? Frequency?)
  - Position the sensors
  - Optimize the number of sensors
- Without having to invest “before” in many costly sensors, physical prototypes and instrumented mock-ups.
- Once a monitoring scenario looks promising, start the physical implementation and tests
Simulation for SHM

Structural Health Monitoring still suffers from a lack of industrial deployment. Why?

Some reasons: Lack of reliability?

- Needs for more performance demonstrations and technical justifications as already required in many NDE sectors and applications
- What are the influential & uncertain parameters?
  Is the monitoring strategy robust:
  - In case of some sensor deficiencies?
  - For many defect sizes, types, locations and orientations?
  - Regarding structural or environmental changes?
- While physical tests can be well suited with a few mock-ups to study the impact of some uncertainties (temperature, ageing, etc.)
- To build a rigorous demonstration performance for all defect scenarios is just too costly with a pure experimental approach
Simulation for SHM

- Structural Health Monitoring still suffers from a lack of industrial deployment. Why?
- Some reasons: What to do with the data?
  - Complex signals to interpret (many modes, dispersive, etc.)
  - Huge amount of data generated
  - Imaging techniques bring one way to help defect identification (detection, location, sizing maybe) and avoid false alarms
Simulation for SHM

You need a model but which model?

- SHM involves network of sensors distributed at different locations on a specimen therefore 3D modelling of guided wave propagation is required

- “Traditional” 3D FEM packages generally produce heavy models difficult to use in real industrial environment (needs skilled users, requiring supercomputers) and leading to very long simulation times
Simulation for SHM

You need a model but which model?

- CIVA SHM has a dedicated and optimized strategy:
  - Based on High Order Spectral Finite Elements method*
  - Mesh is parametrized vs geometric features (specimen, sensors, defects) → “Macro-Mesh” from which the FEM mesh is automatically generated
  - Shows very competitive performances**: A factor 100 versus most of traditional FEM engines!
    (both for computation times and memory footprint → It can work on a classical PC)
- It benefits from the CIVA dedicated user interface and tools (parametric studies, metamodels, scripting)
- CIVA SHM provides imaging tools helping the defect signature interpretation

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Validation

Application case coming from the “Open Guided Wave”* initiative

- Monitored Carbon-Epoxy composite panel
- 16 plies
- 2mm thickness
- 12 Piezo sensors Φ10 mm on both sides of the plate
- Excitation frequency: 40kHz
- Round Robin mode

Validation

Comparison between measurements and simulation data

Good agreement (modal contributions S0 and A0, times of flight, signal shapes, overall amplitudes)

Despite uncertainties (sensor are really close to the edges) and model limitations (attenuation has been neglected)
Applications

Imaging tools highlight the impact of many parameters

- Delay And Sum algorithm: Reconstruction using all signals with and without flaw (\(\Phi 10 \text{ mm} \)) Hole at the center of the specimen) and A0 mode
- **Sensitivity of the distance to edges:**

500mm*500mm specimen: Very bad flaw detection
700mm*700mm specimen: Flaw spot clearly visible
1000mm*1000mm specimen: Good resolution
Imaging tools highlight the impact of many parameters

- **Delay And Sum algorithm**: Reconstruction using all signals with and without flaw (Φ10 mm Hole at the center of the specimen) and A0 mode

- **Impact of different sensors implementation**:

![Linear Layout](image1.png)

![Circle Layout](image2.png)

![2 staggered circles layout: Better SNR](image3.png)
Applications

Imaging tools highlight the impact of many parameters

- **Delay And Sum algorithm**: Reconstruction using all signals with and without flaw (*delamination* at the center of the specimen) and A0 mode
- **Try different sensors (size, frequency):**

![Images of different sensors and their frequency and size](image)

- **40kHz, Φ18 mm sensor**
- **100kHz, Φ18 mm sensor**
- **100kHz, Φ5 mm sensor**
CIVA SHM by guided waves:

- A dedicated simulation tool to help increasing the industrial deployment of Structural Health Monitoring strategies
- Optimized numerical implementation: Much faster than traditional FEM engines and usable on classical computers

More than a competition, there is a complementarity between simulation and experimental approach:

- Experiment: Realistic SNR, Adapted to study the impact of environmental parameters
- Simulation: Low-Cost and Massive parametric studies for multiple monitoring and structural damages situations
Thank you for your attention!

Visit our booth at the exhibition!

Booth #1 in the exhibition hall

Virtual booth: [https://endtcm21.gcon.me/page/home](https://endtcm21.gcon.me/page/home) then:

youtube.com/user/extendechannel

www.extende.com