EUROPEAN NDT&CM2021 PRAGUE, CZECH REPUBLIC OCTOBER 4-7, 2021
BETTER CM & NDT – WARRANTY OF QUALITY, RELIABILITY AND SAFETY

FOUR NDT, CM AND SHM EVENTS IN ONE WEEK IN THE MIDDLE OF THE EUROPE
WE GO HYBRID!

A Simulation Platform for Structural Health Monitoring : CIVA SHM

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EXTENDE CIVA

NDT&CM 2021, October 5th, 2021

Outline

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

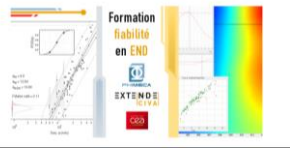
EXTENDE activities

World wide CIVA **DISTRIBUTION** and technical **SUPPORT**

CIVA N·D·E

CIVA N·D·E EDUCATION

CIVA N·D·E



TRAINING COURSES :
CIVA, « Reliability in NDE »

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

CIVA N·D·E

Flux®

Altair | HyperWorks

TRAINDE UT

TRAINDE RT

TraiNDE : Virtual training tool for NDE operators

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EXTENDE CIVA

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

- UT Data **Analysis**

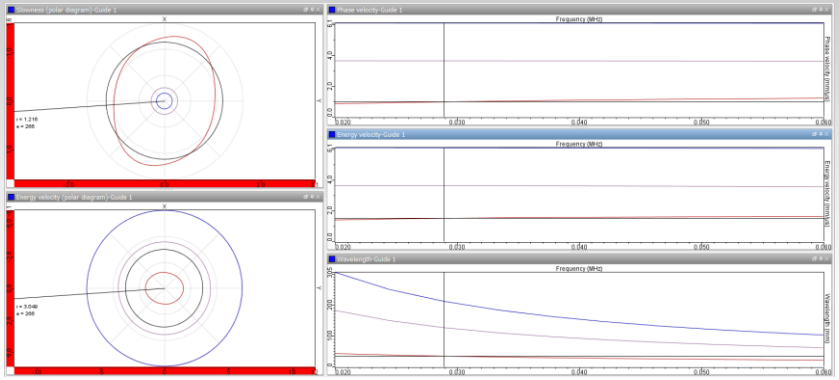
- Developed by R&D Center : **CEA LIST**

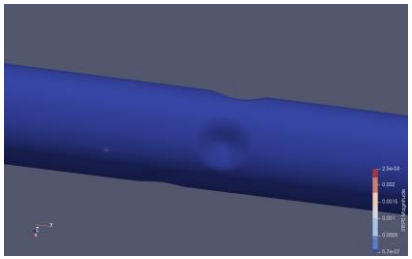
- Exclusive Distribution : **EXTENDE**

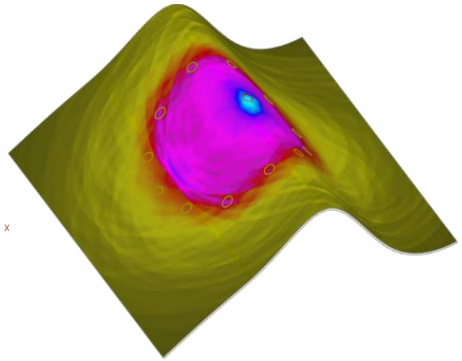
CIVA SHM

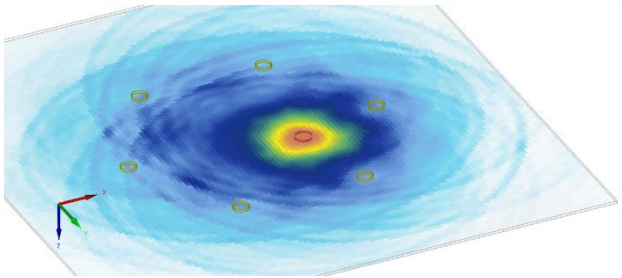
CIVA SHM by Guided Waves includes:

- 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



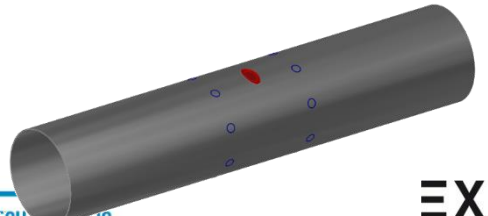


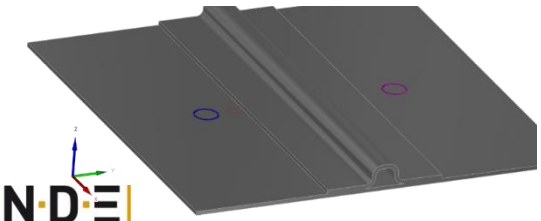


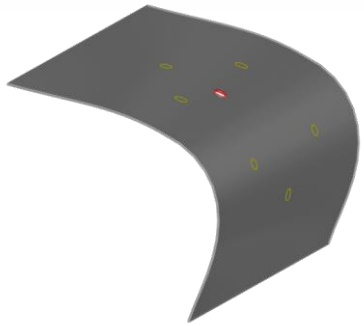


Covers:

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







Simulation for SHM

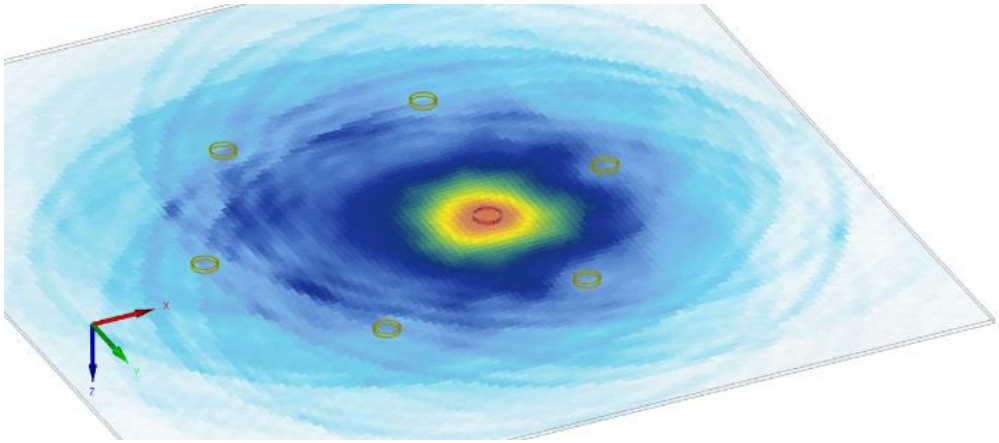
- Structural Health Monitoring still suffers from a lack of industrial deployment. Why ?
- Some reasons: High cost ?
  - Needs to optimize the monitoring setup to find the best compromise “Cost” vs “Number of sensors” vs “Detection performance”
  - Virtual prototyping shall help to :
    - Try and select 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

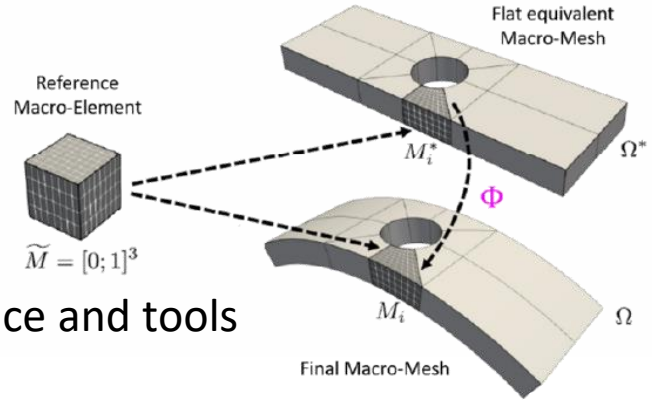
- You need a model but which model ?

  - 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)



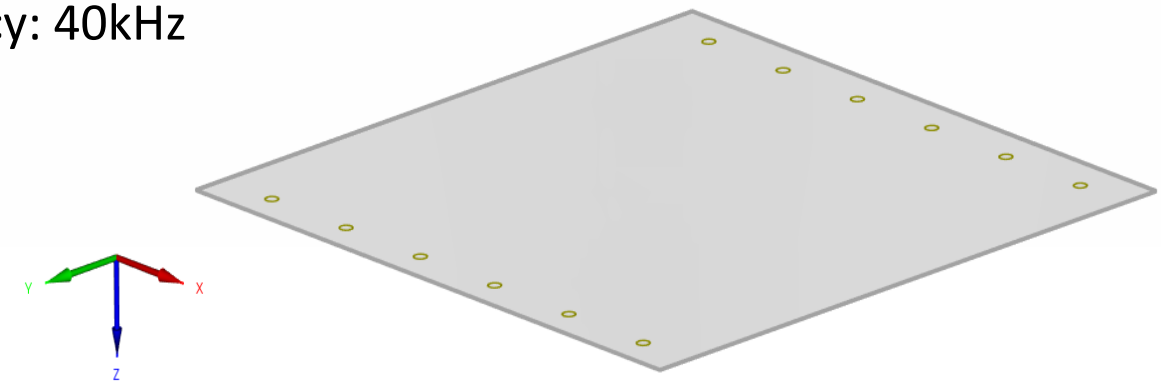
  - It benefits from the CIVA dedicated user interface and tools (parametric studies, metamodels, scripting)
  - CIVA SHM provides imaging tools helping the defect signature interpretation

Imperiale, A., Demaldent, E. (2019**). A macro-element strategy based upon spectral finite elements and mortar elements for transient wave propagation modeling. Application to ultrasonic testing of laminate composite materials. Int. Journal for Numerical Methods in Engineering, vol. 119(10), pp. 964–990.*

*** Mesnil, O., Imperiale, A., Demaldent, E., & Chapuis, B. (**2019**, May). Validation of spectral finite element simulation tools dedicated to guided wave based structure health monitoring. In AIP Conference Proceedings (Vol. 2102, No. 1, p. 050018). AIP Publishing LLC.*

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

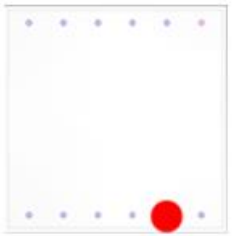


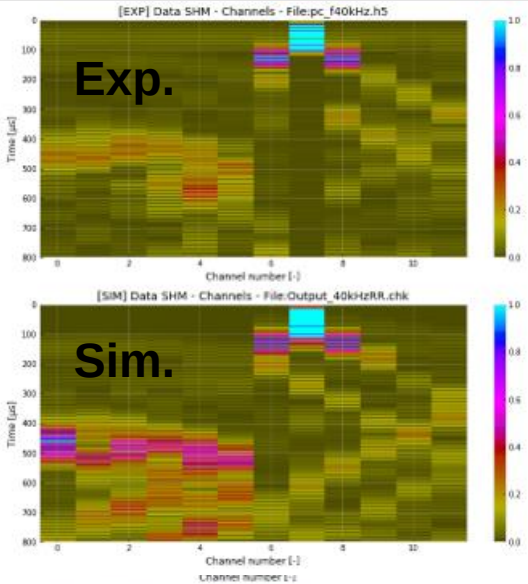
Moll, Jochen, et al. "Open guided waves: online platform for ultrasonic guided wave measurements." Structural Health Monitoring 18.5-6 (2019): 1903-1914. http://openguidedwaves.de

Validation

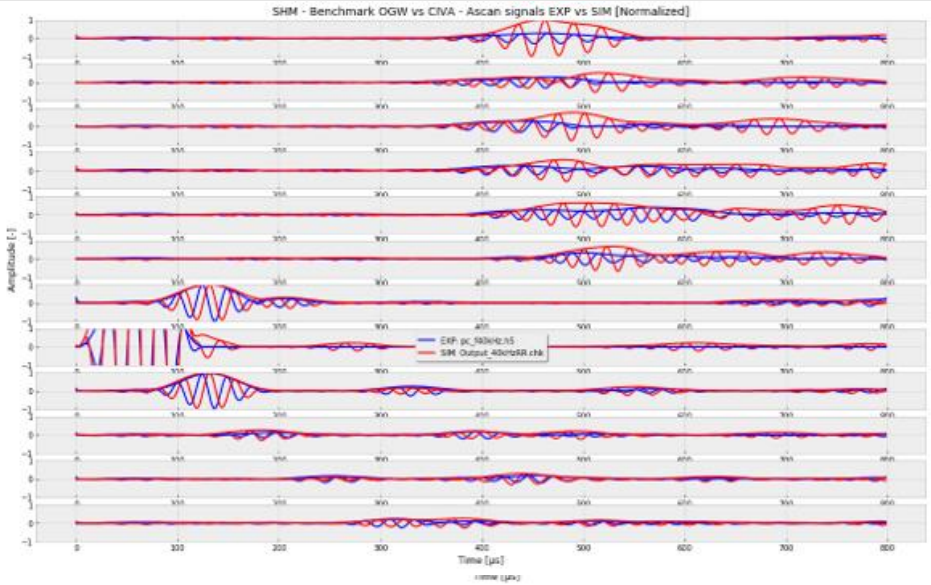
- Comparison between measurements and simulation data

Transmitter #8





B-Scan for 12 channels

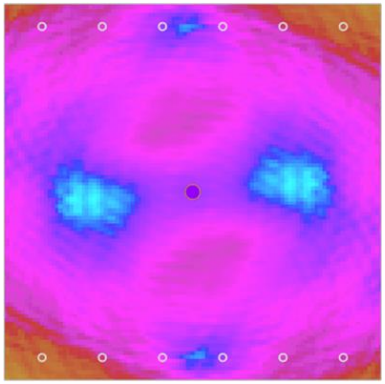


A-Scan for 12 channels (exp. , sim.)

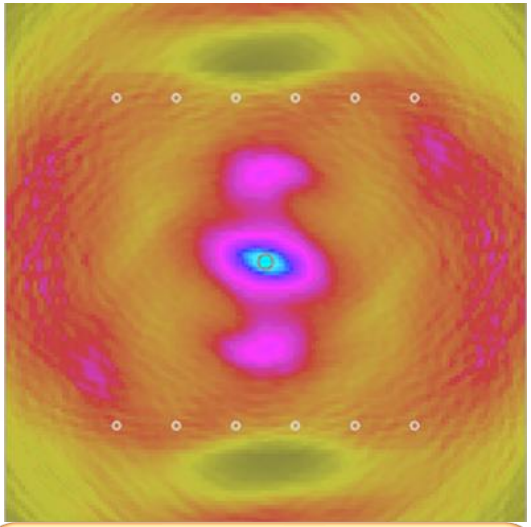
- Good agreement (modal contributions S0 and A0, times of flight, signal shapes, overall amplitudes)
- Despite uncertainties (sensor are really close to the edges) and model limitations (attenuation has been neglected)

Applications

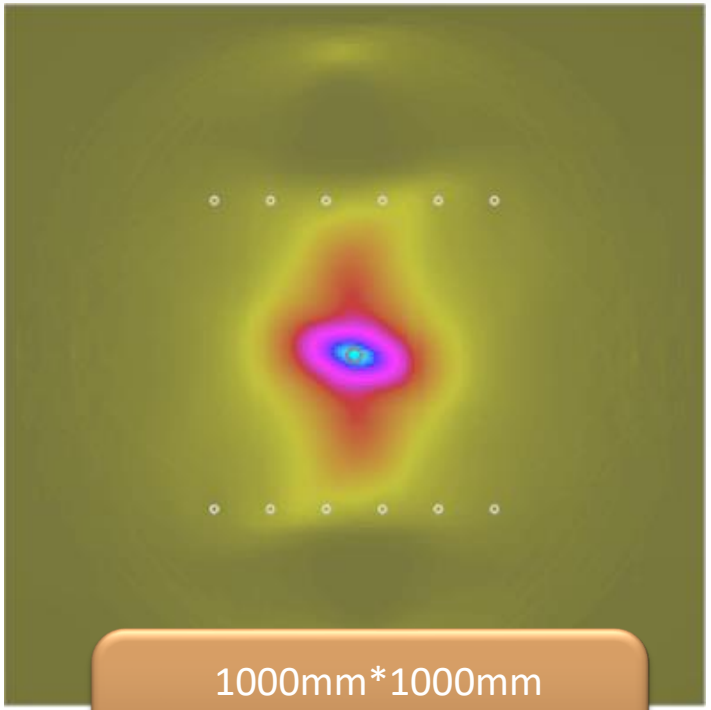
- Imaging tools highlight the impact of many parameters
  - Delay And Sum algorithm: Reconstruction using all signals with and without flaw (Φ10 mm Hole at the center of the specimen) and A0 mode
  - **<u>Sensitivity of the distance to edges :</u>**



500mm*500mm specimen:
Very bad flaw detection



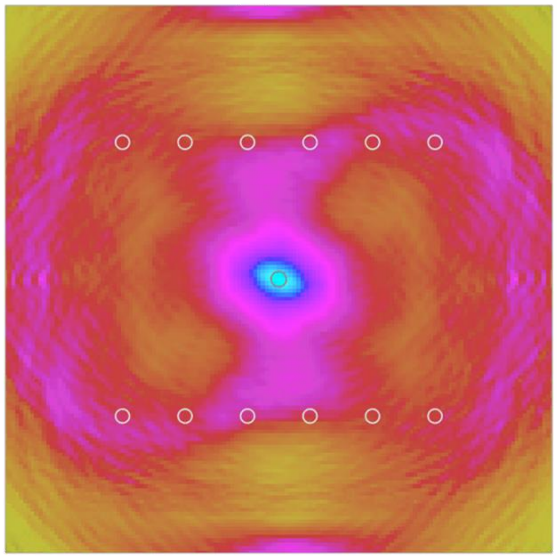
700mm*700mm specimen:
Flaw spot clearly visible



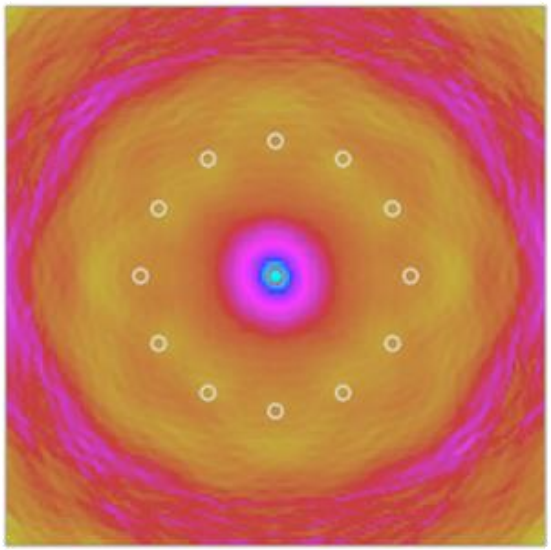
1000mm*1000mm specimen:
Good resolution

Applications

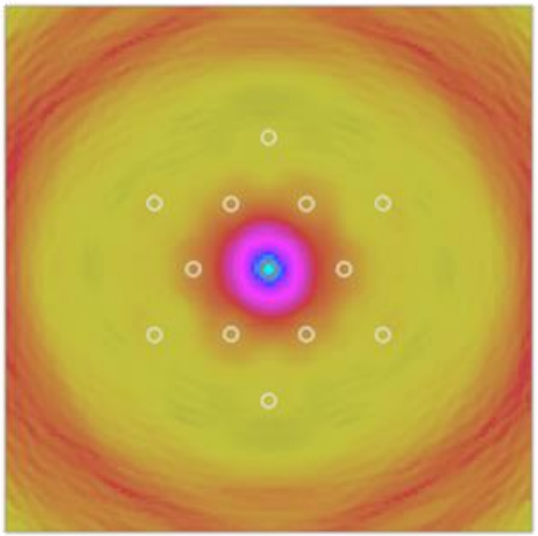
- Imaging tools highlight the impact of many parameters
  - Delay And Sum algorithm: Reconstruction using all signals with and without flaw (Φ10 mm Hole at the center of the specimen) and A0 mode
  - **<u>Impact of different sensors implementation :</u>**



Linear Layout



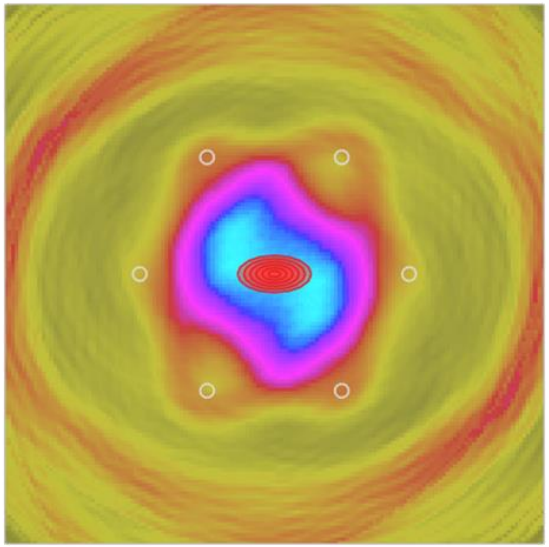
Circle Layout



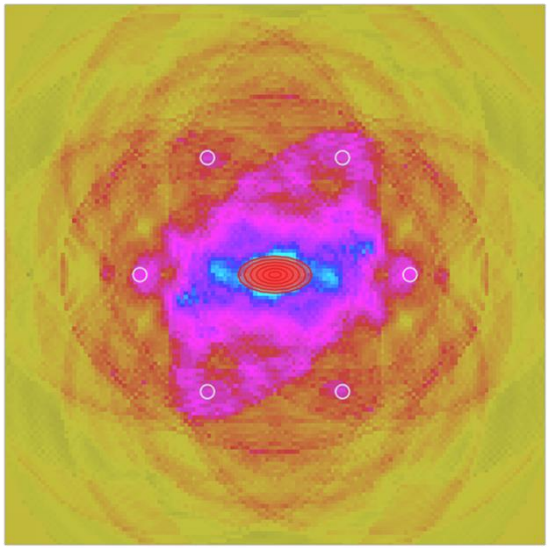
2 staggered circles layout: Better SNR

Applications

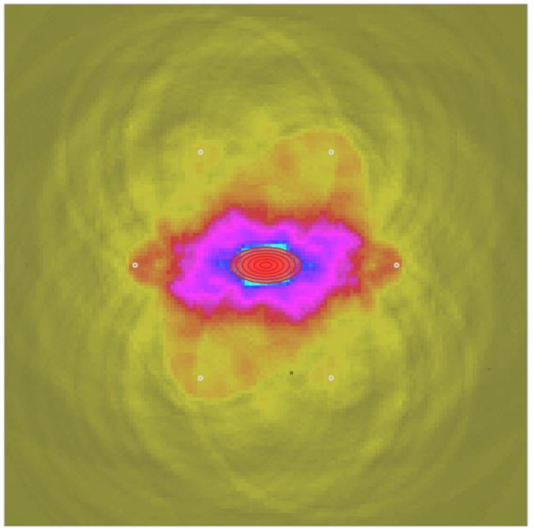
- Imaging tools highlight the impact of many parameters
  - Delay And Sum algorithm: Reconstruction using all signals with and without flaw (**delamination** at the center of the specimen) and A0 mode
  - **<u>Try different sensors (size, frequency):</u>**



40kHz, Φ18 mm sensor



100kHz, Φ18 mm sensor



100kHz, Φ5 mm sensor

Conclusion

- 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 then : EXTENDE CIVA

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