

Time reversal method applied to leaky Lamb waves in an immersed layered medium

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Laboratoire de Mécanique et d'Acoustique







TIME REVERSAL METHOD APPLIED TO LEAKY LAMB WAVES IN

AN IMMERSED LAYERED MEDIUM

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Industrial context

Lamb waves



- Liquid sodium-cooled reactors (SFR-Na) Generation IV
- Periodic inspection using ultrasonic waves (US)
- Internal inspection

(A) Immersion of a TUSHT sensor (wettability, resistance to sodium)

- External inspection
 - (B) Plate-supported guided waves

(C) Guided waves in the main tank and internal structures

➔ Problem statement of this work

Inspection configuration

Lamb waves





<u>Detecting</u> and <u>locating</u> potential defects in an immersed multi-plate system

 \rightarrow Identification of the damaged plate

 \rightarrow Defects: plate edge and notch





- <u>Multimodal</u> nature: multiple modes can coexist at the same frequency
- <u>Dispersive</u> nature: the group velocity of a mode varies over a frequency range

- <u>Imaginary part</u> of the solution of the dispersion equations
- Attenuation by <u>re-emission</u> into the surrounding fluid ⇒ Leaky Lamb Waves (LLW)

Time-reversal cavity

Lamb waves

In a non-dissipative homogeneous medium:

 $\mathbf{L} = \Delta - \frac{1}{c^2} \frac{\partial^2}{\partial t^2}$

- Spatial reciprocity
- Temporal reciprocity
- Huygens-Fresnel principle







Limitations: Simultaneous knowledge of the field and its gradient, diffraction (focal spot), number of sensors ...

Topological energy: calculation steps



1. <u>Numerical resolution</u> of the <u>direct problem</u> in the reference medium:

Inspired by [Dominguez, 2005]

- ightarrow Response of the medium in the equivalent healthy case
- Measurement of the direct problem in the unknown medium:
 → Response of the inspected medium (reference medium + acoustic
- **3.** <u>Numerical resolution</u> of the <u>adjoint problem</u> in the reference medium, with the residual as the source term:
 - → Backpropagation of the **residual**: refocusing at the location of the defect.
- 4. Calculation of topological energy:

signature of the defect)

$$ET(\vec{r}) = \int |u_0(\vec{r},t)|^2 |v_0(\vec{r},t)|^2 dt$$

Dominguez, N., 2005. Time domain topological gradient and time reversal analogy: an inverse method for ultrasonic target detection. Wave Motion 42, 31–52

Topological energy: frequential domain





Protocols

Experimental protocol

Two plates of the same thickness (e = 7,8 mm) Linear array : 16 sensors





Numerical protocol

Frequential topological energy

Radiation patterns calculated on the range [1 kHz ; 700 kHz] with a step of 1 kHz in COMSOL Multiphysics®

Numerical direct problem

Lamb waves



Analysis of the propagation: definition of the 3D-FFT

 τ : the translation parameter of the weighting window



Analysis of the propagation: exploitation of the 3D-FFT

By averaging over the working frequencies for each time step τ :



 \rightarrow The 3D-FFT allows for the selection and temporal isolation of Lamb modes

Measured direct problem

Lamb waves





 τ_1 : time of flight between the two plates (normal direction to the surface)

 τ_2 : time difference of flight between two successive wave packets

→ The most energetic regressive wave packet is isolated and backpropagated

Adjoint problem

Lamb waves



Calculation of the topological energy

Knowing the direct and adjoint fields, the topological energy can be calculated and represented in both plates:



Maximum of topological energy = edge of the second plate

Local maxima are observed and do not correspond to known defect positions

Topological spots (1)

Lamb waves

Superposition of the direct and adjoint problems $\Leftrightarrow ET(\vec{r}) = \int |u_0(\vec{r},t)|^2 |v_0(\vec{r},t)|^2 dt$





Examples:

Topological spots (2)

Lamb waves

The topological energy resulting from the **correlation** of the two fields (direct and adjoint): representation in **spots**



The wave packet selected as the residue: 1st trajectory of the direct problem (1D) Backpropagation of the residue: 1st trajectory of the adjoint problem (1A)

 \rightarrow Intersections 1D/1A (2 solutions)

Influence of the attenuation of the generated mode

• <u>High attenuation</u>: S0 mode at f = 480 kHz

• Intermediate attenuation: A1 mode at f = 480 kHz

• Low attenuation: S1 mode at f = 550 kHz



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Influence of the attenuation of the generated mode (1)



Time [µs]

Low attenuation = detection in the 1st plate High attenuation = detection in the 2nd plate

100

1000

Time [µs]



Influence of the attenuation of the generated mode (2)

Intermediate attenuation



 \rightarrow The two wave packets A and B are isolated and backpropagated independently

Time reversal

along the plate [cm]

Position a

Conclusions



Influence of the attenuation of the generated mode (3)



Intermediate attenuation (Wave packet B)



Conclusions & perspectives

Lamb waves

- We can **locate** a defect in the second plate hidden by the first one
- The concept of **topological spots** has been introduced
- The study of topological spots allowed <u>discrimination of the main image</u> of the detected defect among the secondary images
- The influence of attenuation has been discussed

Perspectives :

• Potential for more complex systems (3 plates, different thickness..)

Identification of defect nature and dimensioning
 → Study of Lamb waves mode <u>conversion</u>

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