Vibration – Acoustics Laboratory

Festival of light

Golden Head park
Staff:

- 4 professors + 1 open position
- 6 assistant professors
- 2 engineers
- 1 technician
- 2 secretaries
- 9 PhD students
- 8 Masters students

Key research areas:

- Sound transmission and radiation
- Mid-frequency modelling
- Source identification / characterisation
- Sound perception

Hot topics:

- Time reversal
- Mems
Sound transmission and radiation
- Modelling of sound radiation
- Fluid / structure coupling
- Acoustic transparency of panels
- Active control of sound transmission

Mid-frequency modelling
- Improved SEA
- Hybrid modelling
- Energy mobility
- Intensity potential approach

Source identification / characterisation
- Inverse methods in vibro-acoustics
- Sources of vibration and pressure pulsation
- Vibration and acoustic sub-structuring
- Vibration diagnosis / acoustical holography

Sound perception
- Subjective assessment of industry noise
- Coupling between vibratory and acoustic stimuli
- Structural parameters versus noise perception
- Preference Models
Direct industrial funding
• Cars (Renault, PSA, Volvo trucks),
• Aeronautics (Airbus),
• Navy (DCNS,DGA),
• Buildings (Lafarge, St Gobain)
• Mems (CEA Leti)

Public funding:
• Rhône-Alpes Region
• National Predit programme
• EU – PCRD programme
• Carnot Institute

City hall
Using Structures as Sensors for source Characterization
Summary

• Introduction
• The RIFF method: basic examples
• Regularization
• The RIFF method with lost information
• The RIFF method: using the weak formulation
• Application to turbulent boundary layer excitation
• Perspectives and Conclusion
Introduction

Is it possible to use the structure vibrations to measure the external boundary pressure?
Basic example of Beam Bending Vibrations

\[ F_{xx} \rho S \omega \Delta = EI \]

5 vibration points → 1 Force point
Basic example of Plate Bending Vibrations
Calculated Vibration field

Force distribution
What happens when measurement uncertainties are considered?

Calculated Vibration field with simulated uncertainty (1% of noise)

Force distribution
Regularization technique

Art of illusion
Trompe l’œil
Regularization

\[
\begin{bmatrix}
L_{j,i}
\end{bmatrix}
\begin{Bmatrix}
W_i
\end{Bmatrix} = \begin{Bmatrix}
F_j
\end{Bmatrix}
\]
Tikhonov regularization

\[
\min \left( \left\| \left[ L_{j,i} \right]^{-1} \{ F_j \} - \{ W_i \} \right\|^2 + \alpha^2 \left\| \{ \hat{F}_j \} \right\|^2 \right)
\]

To select an optimum regularization parameter: a graphical tool, the L curve.
Calculated Vibration field with simulated uncertainty (1% of noise)

Regularized Force distribution
The RIFF method with lost information
Lost information, example of cylinders

\[
\frac{Eh}{1-\nu^2} [L] \begin{bmatrix} u \\ v \\ w \end{bmatrix} + \rho h \omega^2 \begin{bmatrix} u \\ v \\ w \end{bmatrix} = \begin{bmatrix} F_u \\ F_v \\ F_w \end{bmatrix}
\]

\[
[L] = \begin{bmatrix}
\frac{\partial^2}{\partial x^2} + \frac{1-\nu}{2a^2} \frac{\partial^2}{\partial \theta^2} & \frac{1+\nu}{2a} \frac{\partial^2}{\partial x \partial \theta} & \frac{\nu}{a} \frac{\partial}{\partial x} \\
\frac{1+\nu}{2a} \frac{\partial^2}{\partial x \partial \theta} & \frac{\partial^2}{a^2} + \frac{1-\nu}{2} \frac{\partial^2}{\partial x^2} & \frac{1}{a^2} \frac{\partial}{\partial \theta} \\
-\frac{\nu}{a} \frac{\partial}{\partial x} & -\frac{1}{a^2} \frac{\partial}{\partial \theta} & -\left( \frac{1}{a^2} + \beta \frac{\partial^4}{\partial x^4} + \frac{2}{a^2} \frac{\partial^4}{\partial x^2 \partial \theta^2} + \frac{1}{a^4} \frac{\partial^4}{\partial \theta^4} \right)
\end{bmatrix}
\]
Lost information, problem of cylinders

\[
\frac{Eh}{1-v^2} \begin{bmatrix} u \\ v \\ w \end{bmatrix} + \rho h \omega^2 \begin{bmatrix} u \\ v \\ w \end{bmatrix} = \begin{bmatrix} u \\ v \\ F_w \end{bmatrix} = 0 \quad \begin{bmatrix} X_u \\ X_v \\ F_w \end{bmatrix} \rightarrow - \left( \frac{w}{a^2} + \beta \frac{\partial^4 w}{\partial x^4} + \frac{2}{a^2} \frac{\partial^4 w}{\partial x^2 \partial \theta^2} + \frac{1}{a^4} \frac{\partial^4 w}{\partial \theta^4} \right) = F_w
\]
The RIFF method: using the weak formulation
Using the weak formulation

\[
EI \frac{\partial^4 w}{\partial x^4} - \rho S \omega^2 w = 0, \forall x \in [a, b]
\]

\[
\int_a^b \left[ EI \frac{\partial^4 w}{\partial x^4} - \rho S \omega^2 w \right] \eta(x) \, dx = 0, \forall \eta(x)
\]

strong formulation \hspace{2cm} \text{weak formulation}

After integration by part:

\[
\int_a^b w(x) \left[ \rho S \omega^2 \eta(x) - EI \frac{\partial^4 \eta}{\partial x^4}(x) \right] \, dx = T(b)\eta(b) - T(a)\eta(a) - M(b)\frac{\partial \eta}{\partial x}(b) + M(a)\frac{\partial \eta}{\partial x}(a)
\]

\[
+ EI \frac{\partial^2 \eta}{\partial x^2}(b) \frac{\partial w}{\partial x}(b) - EI \frac{\partial^2 \eta}{\partial x^2}(a) \frac{\partial w}{\partial x}(a) - EI \frac{\partial^3 \eta}{\partial x^3}(b) w(b) + EI \frac{\partial^3 \eta}{\partial x^3}(a) w(a)
\]
Using the weak formulation to obtain boundary shear force

Choosing a particular test function

\[ T(b)\eta(b) - T(a)\eta(a) - M(b)\frac{\partial \eta}{\partial x}(b) + M(a)\frac{\partial \eta}{\partial x}(a) \]

\[ + EI \frac{\partial w}{\partial x}(b)\frac{\partial^2 \eta}{\partial x^2}(b) - EI \frac{\partial w}{\partial x}(a)\frac{\partial^2 \eta}{\partial x^2}(a) - EIw(b)\frac{\partial^3 \eta}{\partial x^3}(b) + EIw(a)\frac{\partial^3 \eta}{\partial x^3}(a) \]

\[ = \int_{a}^{b} w(x) \left[ \rho S \omega^2 \eta(x) - EI \frac{\partial^4 \eta}{\partial x^4}(x) \right] dx \]
Using the weak formulation to obtain boundary shear force

Choosing a particular test function

\[ T(a)\eta_T(a) = -\int_a^b w(x) \left[ \rho S \omega^2 \eta_T(x) - EI \frac{\partial^4 \eta_T}{\partial x^4}(x) \right] dx \]

\[ \eta_T(x) = 1 - 35 \frac{(x-a)^4}{(b-a)^4} + 84 \frac{(x-a)^5}{(b-a)^5} - 70 \frac{(x-a)^6}{(b-a)^6} + 20 \frac{(x-a)^7}{(b-a)^7} \]
Experimental Validation

A: Limit due to integration length
C: Limit due to the measurement mesh

No regularization is needed!
Taking into account uncorrelated excitations
Taking into account uncorrelated excitations

Lumière brothers
perspectives

1) Force distribution measurement using an Aray of microflownns sensor

2) Use RIFF technique with finite element model to identify internal sources in machinery or engines:
large number of mesh points necessitate condensing the FE model (**Craig-Bampton**)
3) Use piezoelectric materials with adapted shape to calculate the weak formulation integral giving the shear force, the bending moment, the displacement,..
4) Detecting structural defects as ‘anti forces'
Frequency: 1603 Hz

Measured Velocities are injected in a FEModel with dynamic condensation of rotations

Tikhonov regularisation coupled to L-curve criteria
Results (3/6)

Results with no regularisation – 1603 Hz

Identified Forces

L-curve

(green circle denotes chosen regularisation parameter)
Results (4/6)

Results undersmoothed – 1603 Hz

Identified Forces

L-curve

(green circle denotes chosen regularisation parameter)
Results (5/6)

Results before optimal regularisation – 1603 Hz

Identified Forces

L-curve

(green circle denotes chosen regularisation parameter)
Results (6/6)

Results oversmoothed – 1603 Hz

Identified Forces

L-curve
(green circle denotes chosen regularisation parameter)