EXCERPT FROM:

Damping Models for Shear Beams with Applications to Spacecraft Wiring Harnesses

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Presenting a new viscous damping model for shear beams that yields approximately constant modal damping

Shear Beam & Model Development

Damping Model Results

Ardelean et al. (2010)
http://upload.wikimedia.org/wikipedia/commons/thumb/e/e4/Plate_theory.svg/500px-Plate_theory.svg.png
Power & data cables modify spacecraft dynamics, especially at high frequency

- Cabling can account for 30% of spacecraft dry mass!
  - Increasing power / data reqts
  - Decreasing density of structure
- Accurate dynamics model is essential for spacecraft design
  - Launch loads
  - Precision control
- Current models (structure only) over-predict response levels
  - Cables add damping
- Ground testing can augment models, but is incomplete

Ardelean et al. (2010)
Spacecraft & cable dynamics are coupled through cable tiedowns

Goodding (2008)
Ardelean et al. (2010)
Cables are modeled using effective stiffnesses determined experimentally

- **Extension testing:** $EA$
- **Lateral testing:** $EI$ & $\kappa G$

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Sandia NL — Ardelean et al. (2010)
Experimental results show that modal damping is approximately constant.

- 12 families
- 100 cables
Cables modeled as shear beams initially with “structural” damping

- By researchers at Sandia / AFRL / CSA Engineering / Schafer Corp.
  - Goodding, Ardelean, Babuška, Coombs, et al. (2008-2011)

- Predicts natural frequencies, but damping model is inadequate

- Time-domain model essential
  - Transients & impact response
  - Nonlinearities

- Ideal: ~constant damping
  - Higher damping in higher modes to reduce response

\[ w = \text{transverse displacement} \]
\[ \varphi = \text{rotation due to bending} \]
\[ \beta = \text{shear angle} \]
Shear- and bending-related damping terms yield good results

- Introduce two internal shear forces for damping
  - Associated with time rate of change of shear & bending angles
    \[ V = -\alpha_\beta \dot{\beta} - \alpha_\phi \dot{\phi} \]

- EOM with damping
  \[ -\rho A \ddot{w} + \kappa AG (\varphi' + w'') = -q - \alpha_\beta \dot{\beta}' - \alpha_\phi \dot{\phi}' \]
  \[ EI \varphi'' + \kappa AG (\varphi + w') = 0 \]

- Shear- and bending-related damping contributions are explicitly separated
  \[ \zeta_m = \frac{1 + \alpha_\beta \varepsilon m^2}{2\sqrt{\rho AEI}} \frac{\alpha_\phi}{\sqrt{1 + \varepsilon m^2}} \]
  \[ \zeta_m \sim \begin{cases} \frac{\alpha_\phi}{\varepsilon m^2} << 1 \\ \alpha_\beta m \varepsilon m^2 >> 1 \end{cases} \]
A range of damping trends available from choice of shear & bending terms

\[ \frac{\alpha_{\beta}}{\alpha_{\varphi}} = 1 \]
\[ \frac{\alpha_{\beta}}{\alpha_{\varphi}} = \frac{3}{4} \]
\[ \frac{\alpha_{\beta}}{\alpha_{\varphi}} = \frac{1}{2} \]
\[ \frac{\alpha_{\beta}}{\alpha_{\varphi}} = \frac{1}{4} \]
\[ \frac{\alpha_{\beta}}{\alpha_{\varphi}} = 0 \]

Normalized Modal Damping

Mode Number m
Proposed model with motion-, shear-, and bending-based terms fits data well.

\[ \alpha_M = 0.043 \]
\[ \alpha_\phi = 0.038 \]
\[ \frac{\alpha_\beta}{\alpha_\phi} = 0.3 \]
Time-domain damping model for shear beams captures dynamics of spacecraft cabling

- Behavior can be separated into bending- and shear-dominated regimes
  - Corresponding physical understanding
    $$-\rho Aw + \kappa AG (-\varphi' + w'') = -q - \alpha \beta \dot{\psi}' - \alpha \varphi \dot{\phi}'$$
- Freq-independent modal damping achievable in bending region
  - Can control damping in shear regime
  - Can achieve best possible freq-indep
- Damping model can be readily implemented using FEM
  - Uses conventional $K, K_G, \text{ & } M$ matrices
- Model predictions agree well with experimental data

$$\zeta = \frac{\alpha \varphi}{2\sqrt{\rho AEI}} \left(1 + \frac{\alpha \beta \epsilon m^2}{\alpha \varphi \epsilon m^2}\right)$$
ADAPTIVE STRUCTURES AND NOISE CONTROL

Faculty Members

- George Lesieutre
- Mary Frecker
- Reginald Hamilton
- Zoubeida Ounaies
- Chris Rahn
- Kenji Uchino
Lesieutre projects

• Piezoelectric-based Vibration Reduction of Turbomachinery Bladed Disks via Resonance Frequency Detuning
  – NASA GRC; student: Jeff Kauffman

• Multistate Fluidic Lag Damper
  – Lord Corp (w/ Smith); Conor Marr

• **Damping Models for Spacecraft Wiring Harnesses**
  – AFRL / Sandia; Jeff Kauffman

• Multi-Layered Cylindrical Isolator for Helicopter Gearbox Shaft Isolation
  – Penn State; Pauline Autran

• Variable Thermal Conductivity Structures for Spacecraft Thermal Control
  – AFOSR (w/ Frecker, Adair); Becky Stavely
Piezo-based frequency detuning has potential to improve turbine blade life

- Reduced response needed in blisks
  - Conventional damping unsuccessful

- Use “switchable” piezo stiffness to de-tune blade freqs from excitation
A layered cylindrical isolator has the potential to reduce helicopter interior noise (shaft / GB housing)

- Seek a stop-band from 500-2000 Hz
- End of band defined by thickness modes
- Start of band complex relative to 1-D isolators
- Assumed-modes model for rapid analysis
Dr. Frecker's research projects focus on optimal design & fab of compliant mechanisms for medical & aerospace apps

1 mm Compliant Forceps

Collaborators:
Dr. J. Adair, MSE
Dr. C. Muhlstein, MSE
Dr. R. Haluck, Surgery
Dr. A. Mathew, Gastroenterology

Students:
Milton Aguirre
Greg Hayes

Sponsor: NIH NIBIB

Cellular Contact-Aided Compliant Mechanisms

Collaborators:
Dr. J. Adair, MSE
Dr. G. Lesieutre, AeroE

Students:
Vipul Mehta
Samantha Cirone
Greg Hayes

Sponsor: NSF CMII

Compliant Spine for Passive Morphing of Ornithopter Wings

Collaborator:
Dr. J. Hubbard, U. Maryland

Student: Yash Tummala

Sponsor: AFOSR
Optimization on \( h/l \) and \( \theta \) shows that the best design depends on the input velocity. Contact can increase energy absorption by 65%.

Lower \( h/l \) values due to manufacturing constraints.

Student: Jennifer Hyland
Collaborators:
Dr. J. Adair, MSE
Dr. G. Lesieutre, AeroE
Sponsor: NSF CMII
A nonlinear compliant spine is optimally designed for passive reconfiguration of ornithopters.

Student: Yashwanth Tummala
Collaborator: Dr. James E. Hubbard Jr., UMd
Sponsor: AFOSR
Natural Orifice Transluminal Endoscopic Surgery (NOTES) [1]

References
Shape Memory Alloys: Material Design

Reginald F. Hamilton, PhD
Assistant Professor of Engineering Science and Mechanics
The Electroactive Materials Characterization Laboratory

Zoubeida Ounaies and group
Research Focus

Materials exhibiting electro-mechanical coupling — such as piezoelectric and ferroelectric ceramics, electro-active polymers, and nano-composites — for sensing, actuation, electrical energy harvesting, conversion and storage.
What we do...

Develop, synthesize, process, and characterize new adaptive / smart materials

Capabilities for synthesis and fabrication

Structure-property relationship for Sensing-Actuation-Storage
High Performance Piezoelectric Actuators and Wings for Nano Air Vehicles
  - AFOSR; Kiron Mateti (PhD 2012), Rory Byrne-Dugan (MS 2012)

EFRI-BSBA: Learning from Plants – Biologically-Inspired Multi-Functional Adaptive Structures
  - NSF, Bin Zhu (PhD 2013)

LORD Rotorcraft Center Fellow
  - Lloyd Scarborough (PhD 2012)

Future: battery research