IDENTIFICATION OF STRUCTURAL DAMPING FROM TESTS

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ECERTA Workshop
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Contents

- Objectives of the research
- Energy balance identification method
- Validation (Numerical simulation / Experiments)
- Future and current work

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Objectives of the research

Main sources of energy dissipation in a structure

- Joints (bolts, rivets, welding, supports, bearings, …)

- Material damping (electronic mechanisms, dislocations, relaxation on grain boundaries, irreversible intercrystal heat flux, thermoelastic damping, thermal hysteresis, eddy currents, ferromagnetic hysteresis, …)

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Objectives of the research

$$\mathbf{M}\ddot{\mathbf{x}} + \mathbf{C}\dot{\mathbf{x}} + \mathbf{K}\mathbf{x} = \mathbf{f}(t)$$

Damping

Inertia forces

Viscous damping

Elastic forces

External forces

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Issues in damping identification

- Simplified mathematical model needed

- Computational time

- Incompleteness of data (modal and spatial)

- Generally small effect on dynamics, difficult measurement

Modal and spatial identification

Modal identification:

Modal damping ratio ζ_i

Loss factor η_i

- Logarithmic decrement

- Half-power bandwidth method

Modal and spatial identification

Spatial identification:

Viscous damping matrix $\mathbf{C}$

- Modal parameters $\lambda_n\ ,\ \boldsymbol{\psi}_n$
  (Perturbation methods, Lancaster's formula, …)

- Frequency Response Function $\mathbf{H}(\omega)$
  (Imaginary part of dynamic stiffness matrix, …)

- Time history $\mathbf{x}(t), \dot{\mathbf{x}}(t), \ddot{\mathbf{x}}(t)$
  (Energy balance method, …)

Prandina, M., Mottershead, J.E., and Bonisoli, E., An assessment of damping identification methods, Journal of Sound and Vibration 323(3-5), 2009, pages 662-676.

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Advantages of the energy approach

- Good performance when noise and/or modal incompleteness is present.

- Potential identification of nonlinear damping.

- System model not needed under certain assumptions.

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Theory

The new method is based on the energy balance method, starting from the equations of motion of a MDOF system

$$\mathbf{M}\ddot{\mathbf{x}} + \mathbf{D}\, g(\mathbf{x}, \dot{\mathbf{x}}) + \mathbf{K}\mathbf{x} = \mathbf{f}(t)$$

The energy equation can be derived

$$\int_t^{t+T_1} \dot{\mathbf{x}}^{\mathrm{T}} \left(\mathbf{M}\ddot{\mathbf{x}} + \mathbf{D}\, g(\mathbf{x}, \dot{\mathbf{x}}) + \mathbf{K}\mathbf{x} \right) \mathrm{d}t = \int_t^{t+T_1} \dot{\mathbf{x}}^{\mathrm{T}} \mathbf{f}(t)\, \mathrm{d}t$$

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Theory

In the case of <u>periodic response</u>, the contribution of <u>conservative forces</u> to the total energy over a full cycle of periodic motion is zero. So if $T_1 = T$ (period of the response)

$$\int_t^{t+T} \dot{\mathbf{x}}^{\mathrm{T}} \left(\mathbf{M}\ddot{\mathbf{x}} + \mathbf{K}\mathbf{x} \right) \mathrm{d}t = 0$$

And the energy equation can be reduced to

$$\int_t^{t+T} \dot{\mathbf{x}}^{\mathrm{T}} \mathbf{D}\, g\left(\mathbf{x}, \dot{\mathbf{x}}\right) \mathrm{d}t = \int_t^{t+T} \dot{\mathbf{x}}^{\mathrm{T}} \mathbf{f}\left(t\right) \mathrm{d}t$$

Solve for $\mathbf{D}$

Energy equivalent $\mathbf{D_e}$

Diagonal viscous damping matrix

$$\mathbf{C} = \begin{bmatrix} c_1 & 0 & \cdots & 0 & \cdots & 0 \\ 0 & c_2 & \cdots & 0 & \cdots & 0 \\ \vdots & \vdots & \ddots & 0 & \cdots & 0 \\ 0 & 0 & 0 & c_p & \cdots & 0 \\ \vdots & \vdots & \vdots & \vdots & \ddots & 0 \\ 0 & 0 & 0 & 0 & 0 & c_n \end{bmatrix}$$

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Diagonal viscous damping matrix

The simplest case is a system with diagonal viscous damping matrix. In this case the energy equation becomes

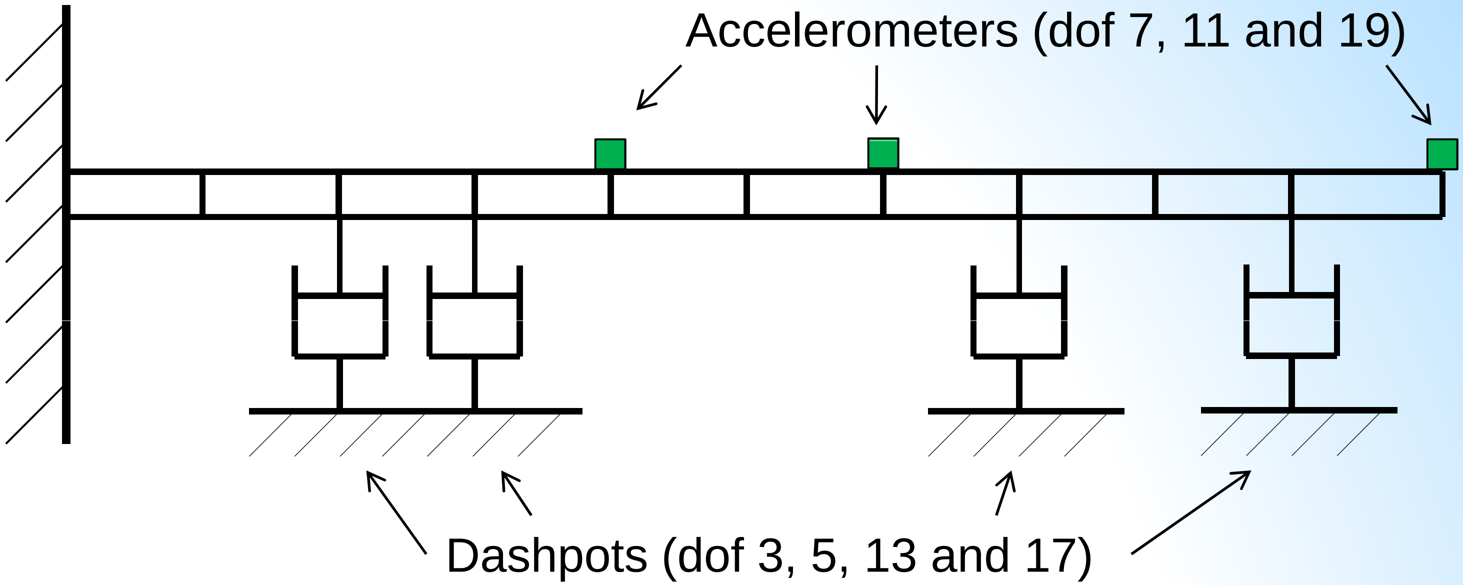
$$\int_{t}^{t+T} \dot{\mathbf{x}}^{\mathrm{T}} \mathbf{C} \dot{\mathbf{x}} \, \mathrm{d}t = \int_{t}^{t+T} \dot{\mathbf{x}}^{\mathrm{T}} \mathbf{f}(t) \, \mathrm{d}t$$

$$c_1 \int_{t}^{t+T} \dot{x}_1^{\,2} \mathrm{d}t + c_2 \int_{t}^{t+T} \dot{x}_2^{\,2} \mathrm{d}t + \ldots + c_n \int_{t}^{t+T} \dot{x}_n^{\,2} \mathrm{d}t = \int_{t}^{t+T} \dot{\mathbf{x}}^{\mathrm{T}} \mathbf{f}(t) \, \mathrm{d}t$$

Diagonal viscous damping matrix

$$\begin{bmatrix} \int_t^{t+T_1} \dot{x}_{1(1)}^{\;2}\,\mathrm{d}t & \int_t^{t+T_1} \dot{x}_{2(1)}^{\;2}\,\mathrm{d}t & \dots & \int_t^{t+T_1} \dot{x}_{n(1)}^{\;2}\,\mathrm{d}t \\ \int_t^{t+T_2} \dot{x}_{1(2)}^{\;2}\,\mathrm{d}t & \int_t^{t+T_2} \dot{x}_{2(2)}^{\;2}\,\mathrm{d}t & \dots & \int_t^{t+T_2} \dot{x}_{n(2)}^{\;2}\,\mathrm{d}t \\ \dots & \dots & \dots & \dots \\ \int_t^{t+T_m} \dot{x}_{1(m)}^{\;2}\,\mathrm{d}t & \int_t^{t+T_m} \dot{x}_{2(m)}^{\;2}\,\mathrm{d}t & \dots & \int_t^{t+T_m} \dot{x}_{n(m)}^{\;2}\,\mathrm{d}t \end{bmatrix} \begin{Bmatrix} c_1 \\ c_2 \\ \dots \\ c_n \end{Bmatrix} = \begin{Bmatrix} \int_t^{t+T_1} \dot{\mathbf{x}}^{\mathrm{T}} \mathbf{f}_1(t)\,\mathrm{d}t \\ \int_t^{t+T_2} \dot{\mathbf{x}}^{\mathrm{T}} \mathbf{f}_2(t)\,\mathrm{d}t \\ \dots \\ \int_t^{t+T_m} \dot{\mathbf{x}}^{\mathrm{T}} \mathbf{f}_m(t)\,\mathrm{d}t \end{Bmatrix}$$

Validation: numerical example



Prandina, M., Mottershead, J.E., and Bonisoli, E., Location and identification of damping parameters, IMAC XXVII Conference and Exposition on Structural Dynamics, Orlando, Florida, USA, 2009.

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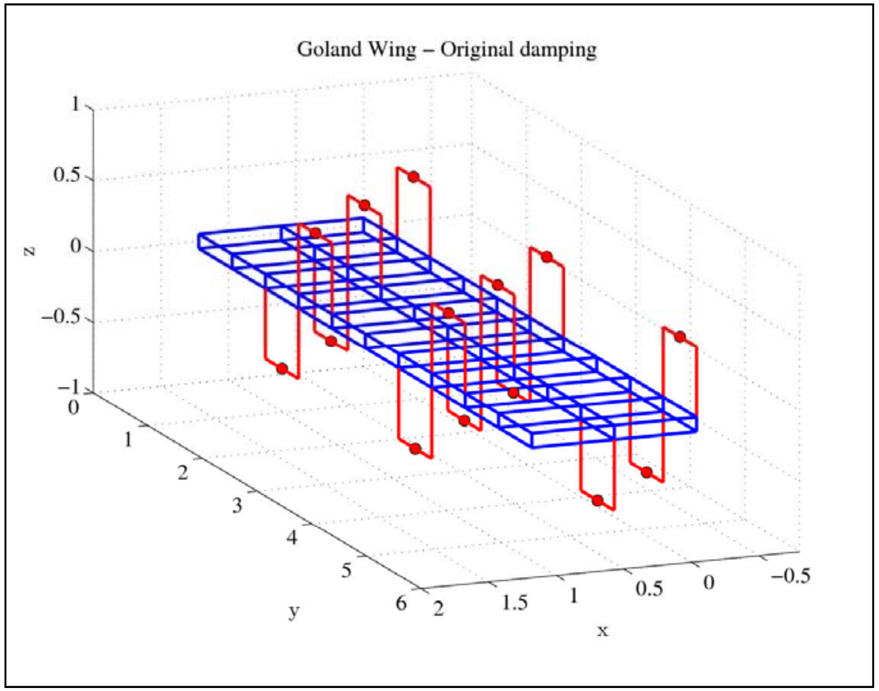
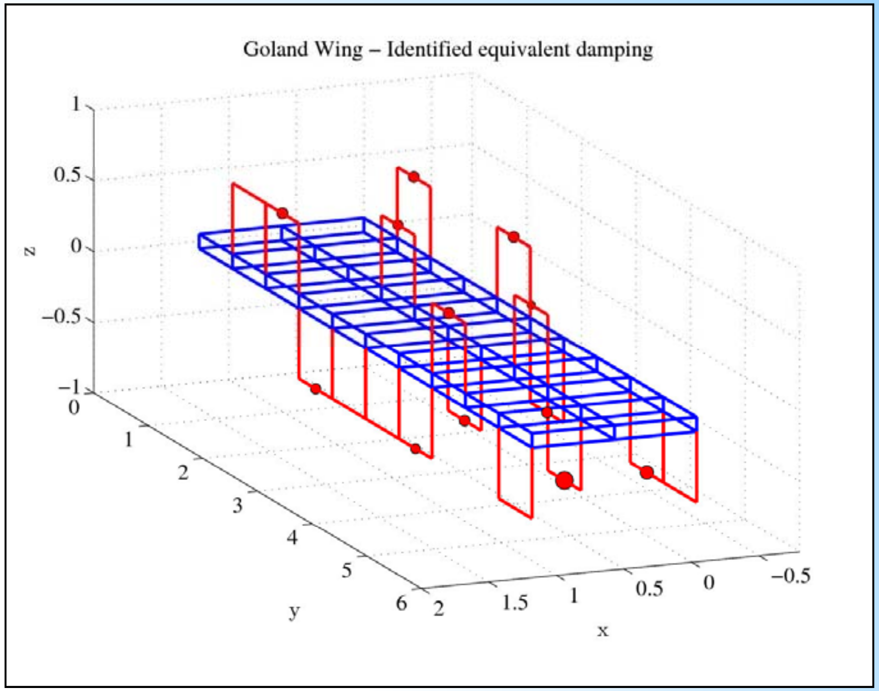
Goland wing





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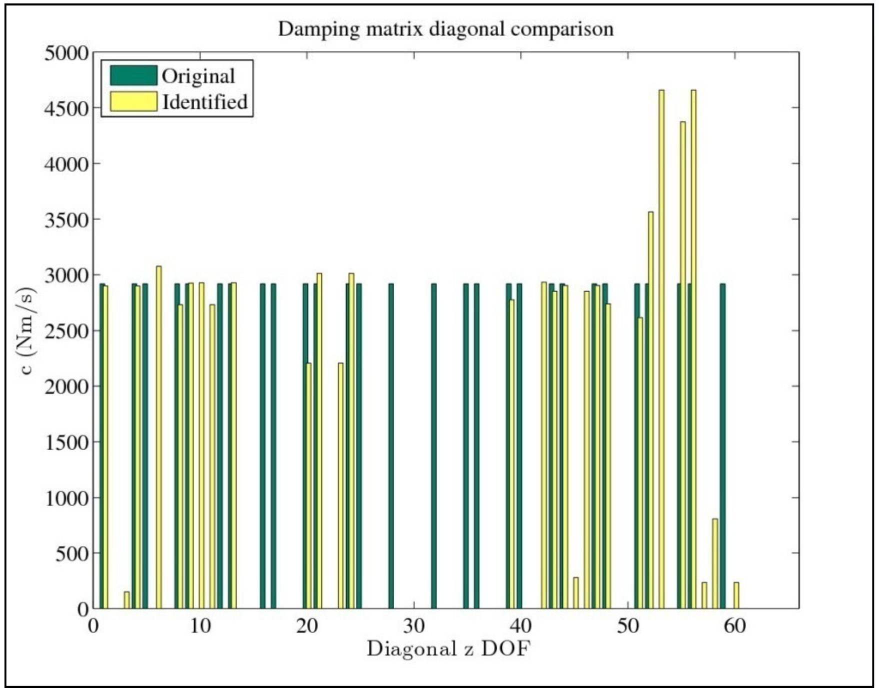
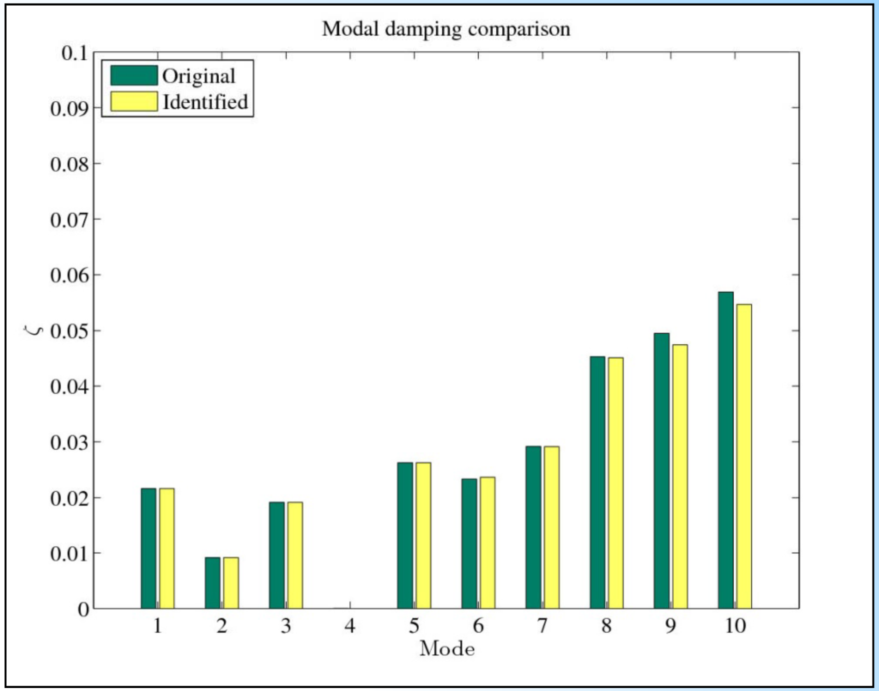
Goland wing simulation





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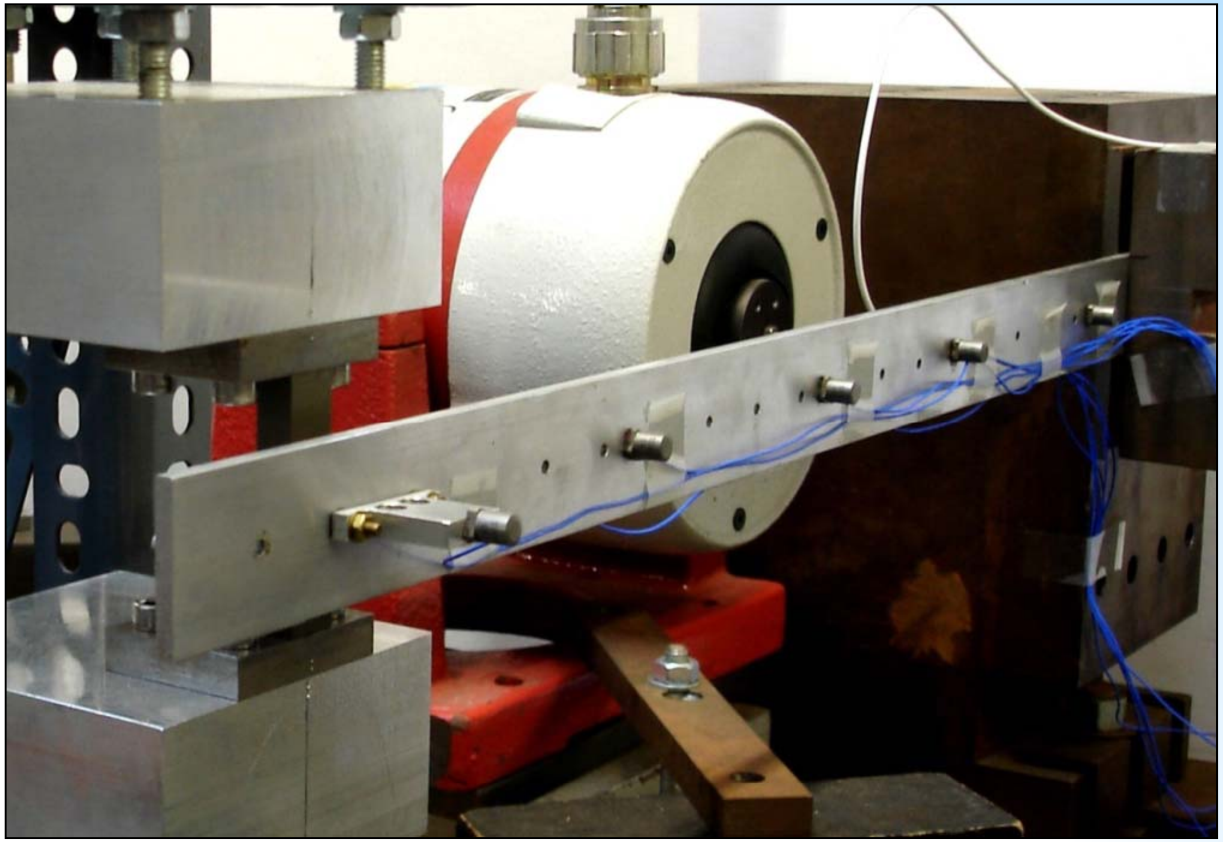
Experiment setup



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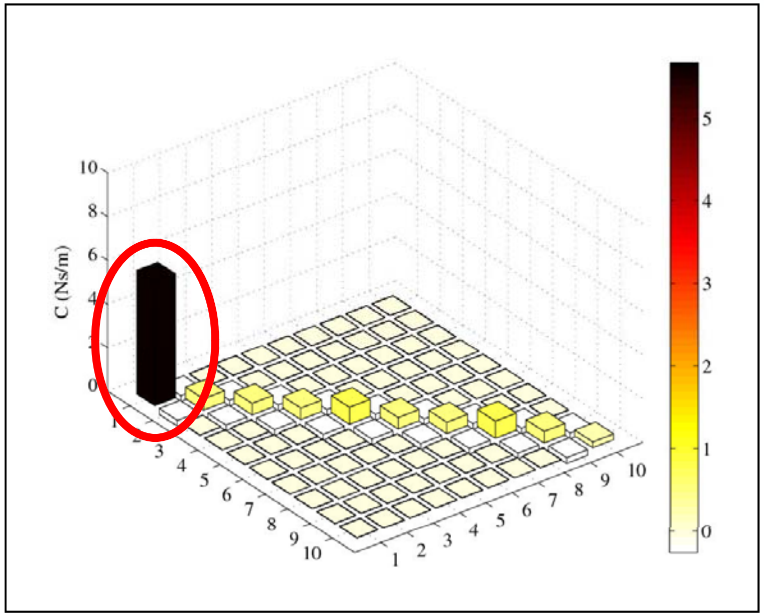
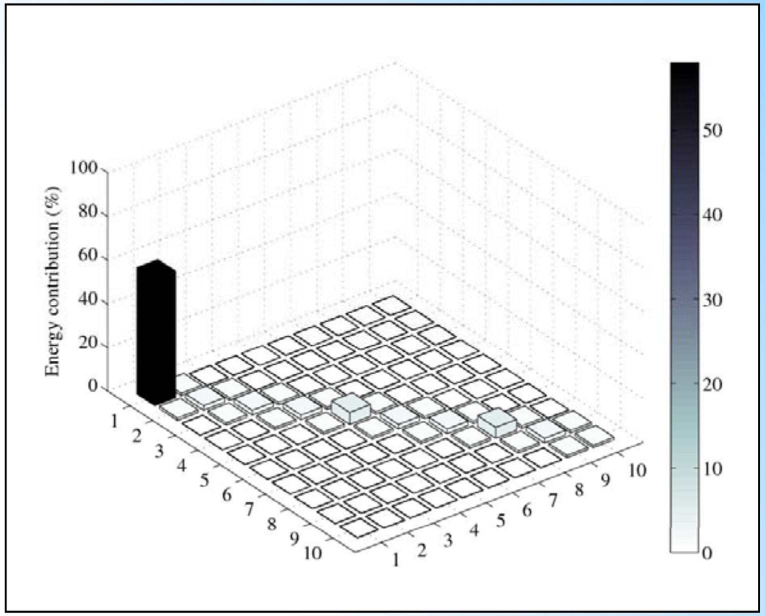
Undamped system

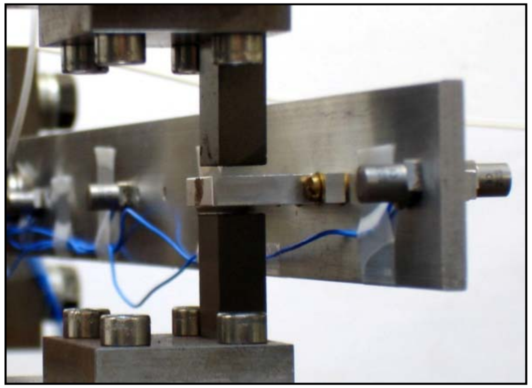


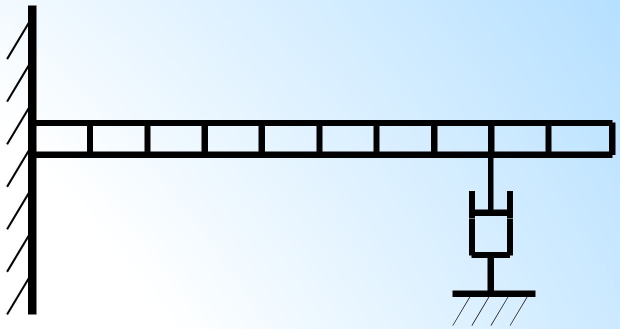
Viscous damping matrix

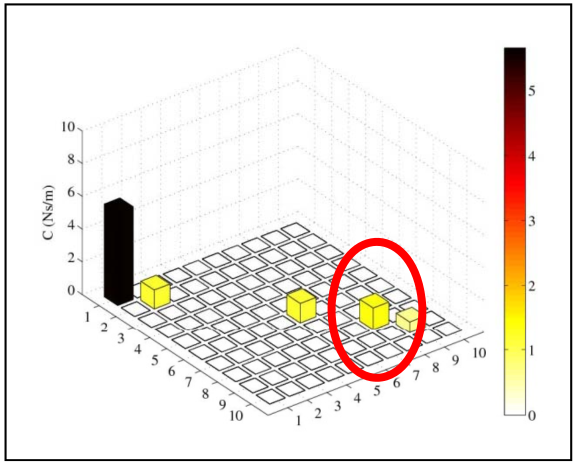


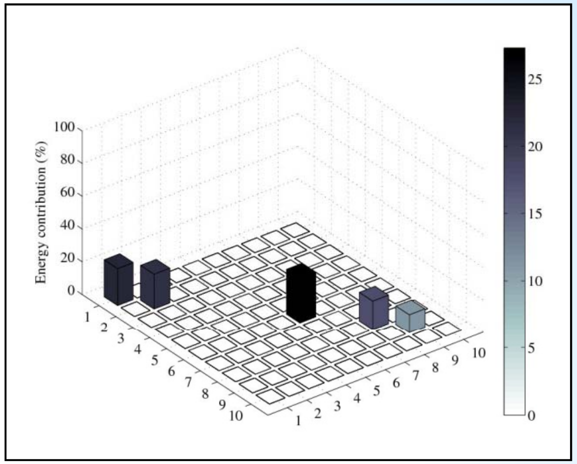
Energy dissipated (%)

Magnetic damping (DOF 8)









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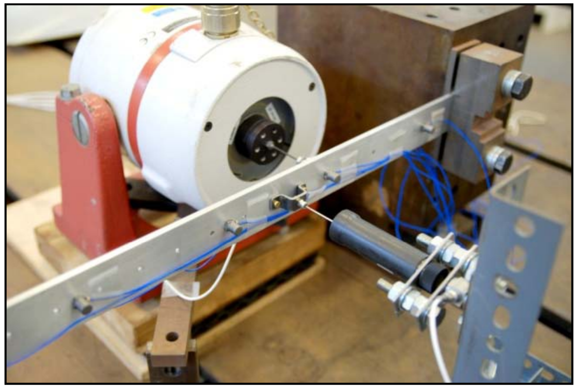
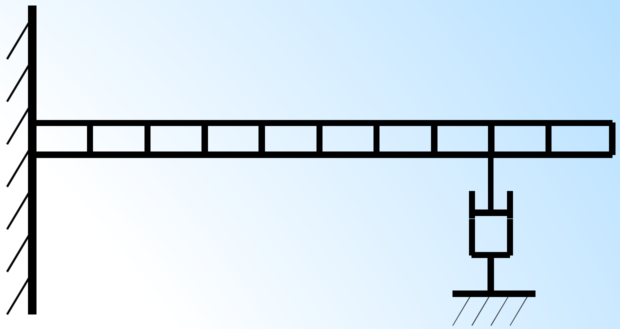
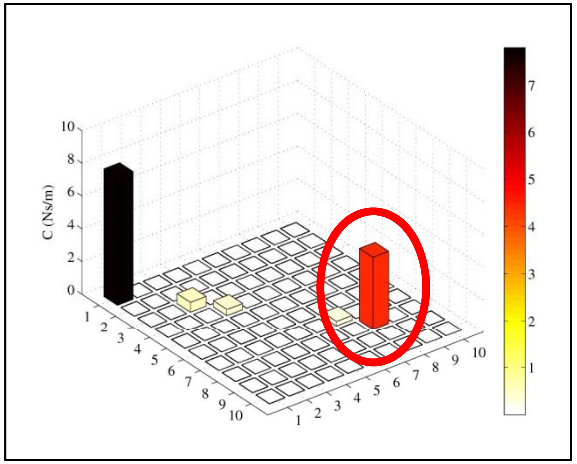
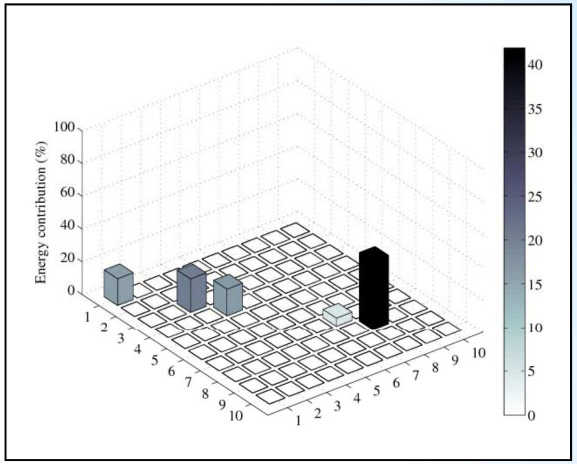
Air dashpot (DOF 8)

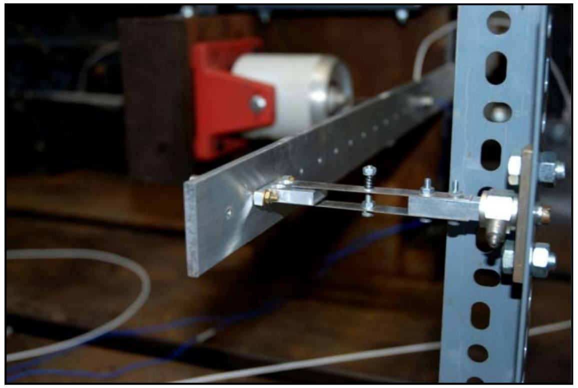


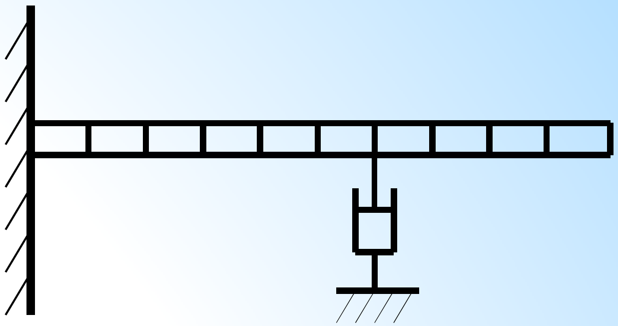


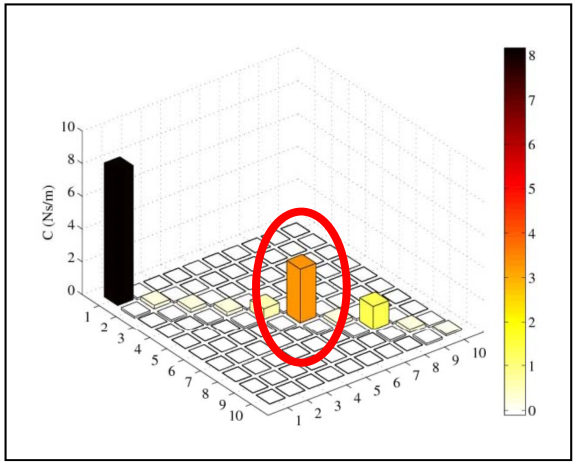


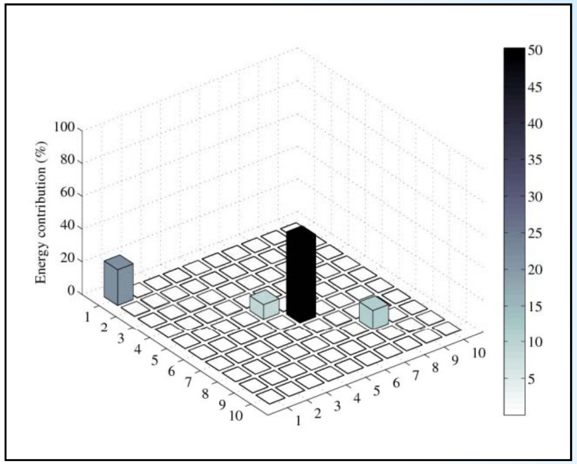


Coulomb friction (DOF 6)









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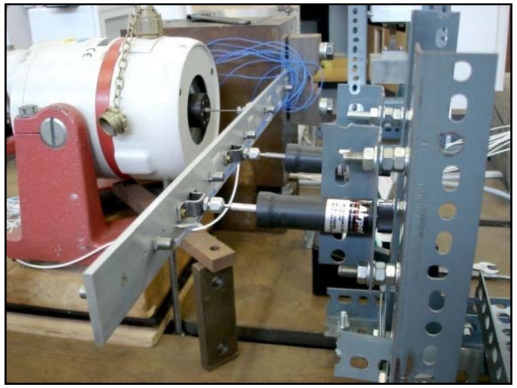
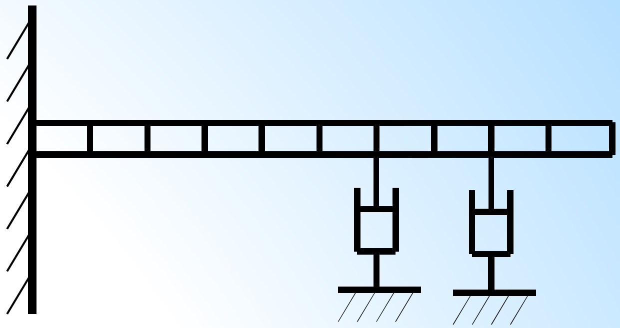
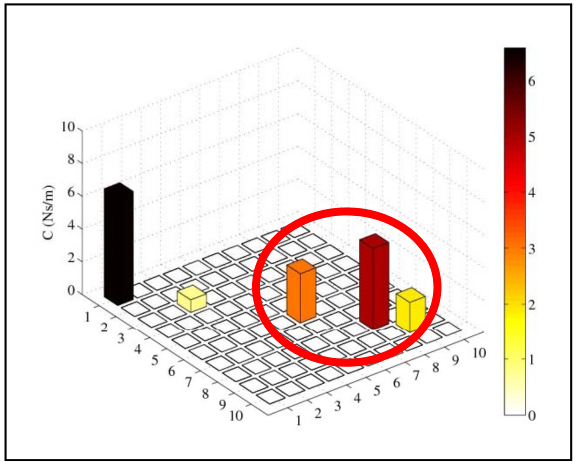
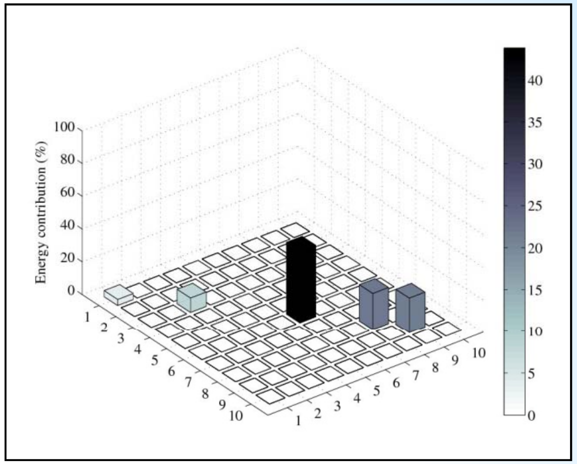
Multiple air dashpots (DOF 6 and 8)









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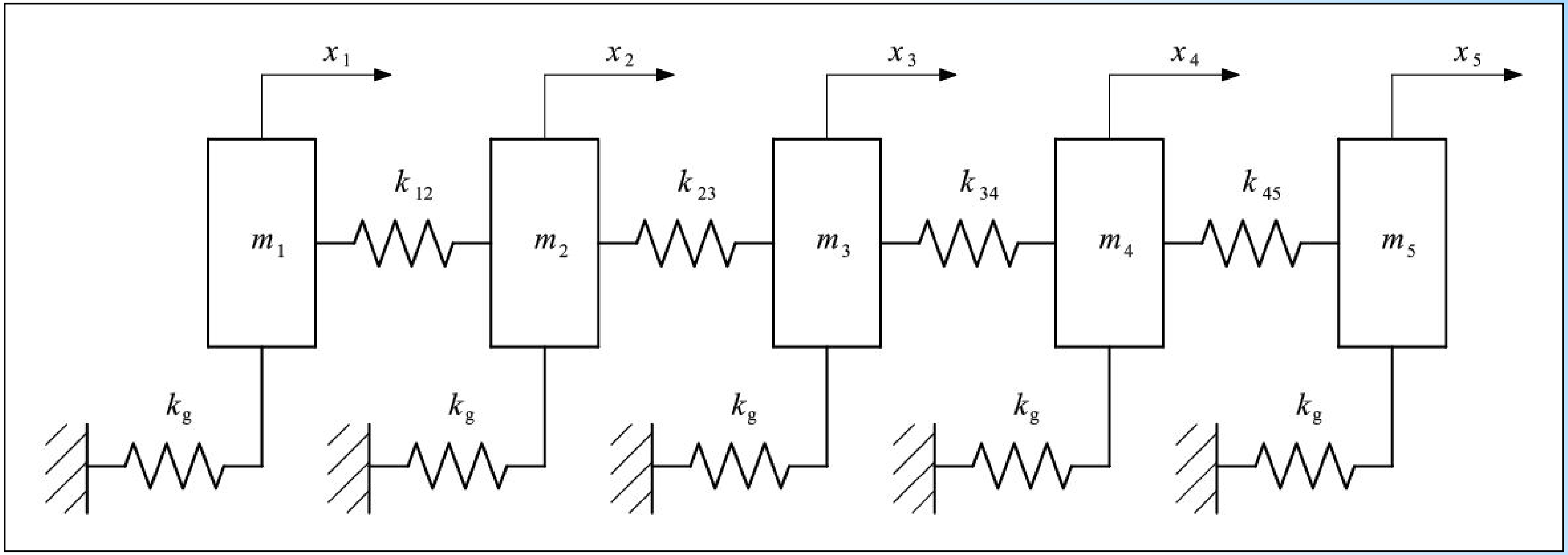
Prandina, M., Mottershead, J.E., and Bonisoli, E., Location and identification of damping parameters, IMAC XXVII Conference and Exposition on Structural Dynamics, Orlando, Florida, USA, 2009.

Experiment 2

5-mass system



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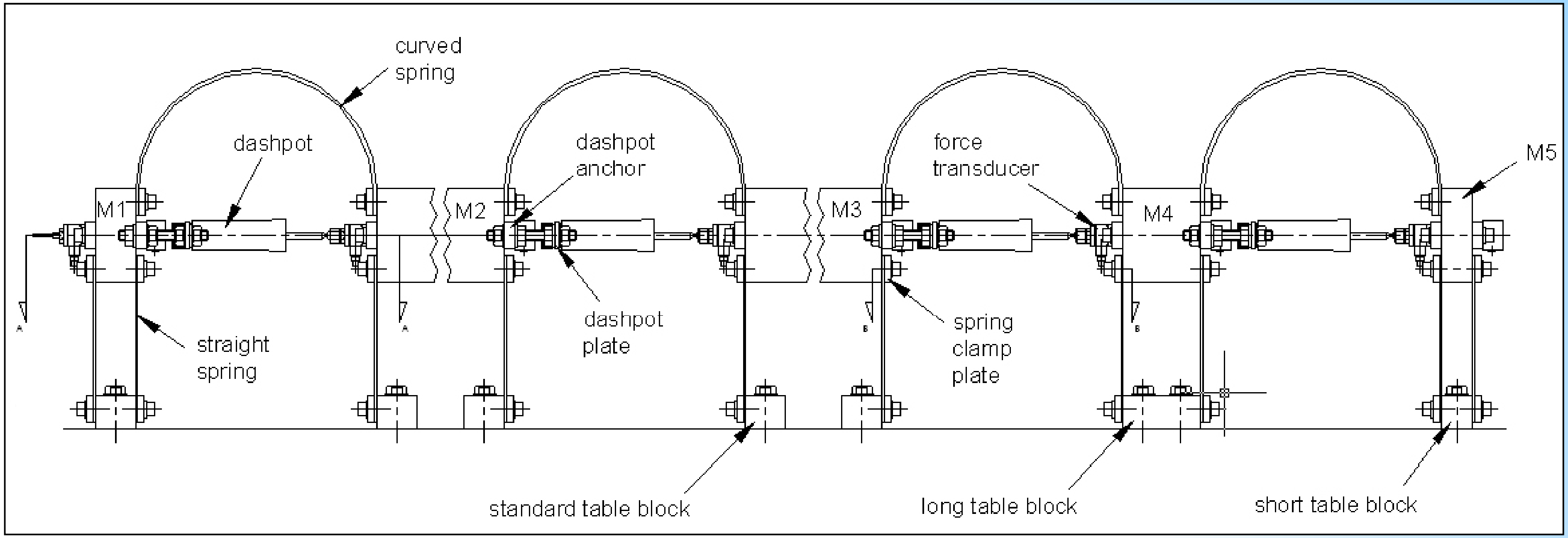
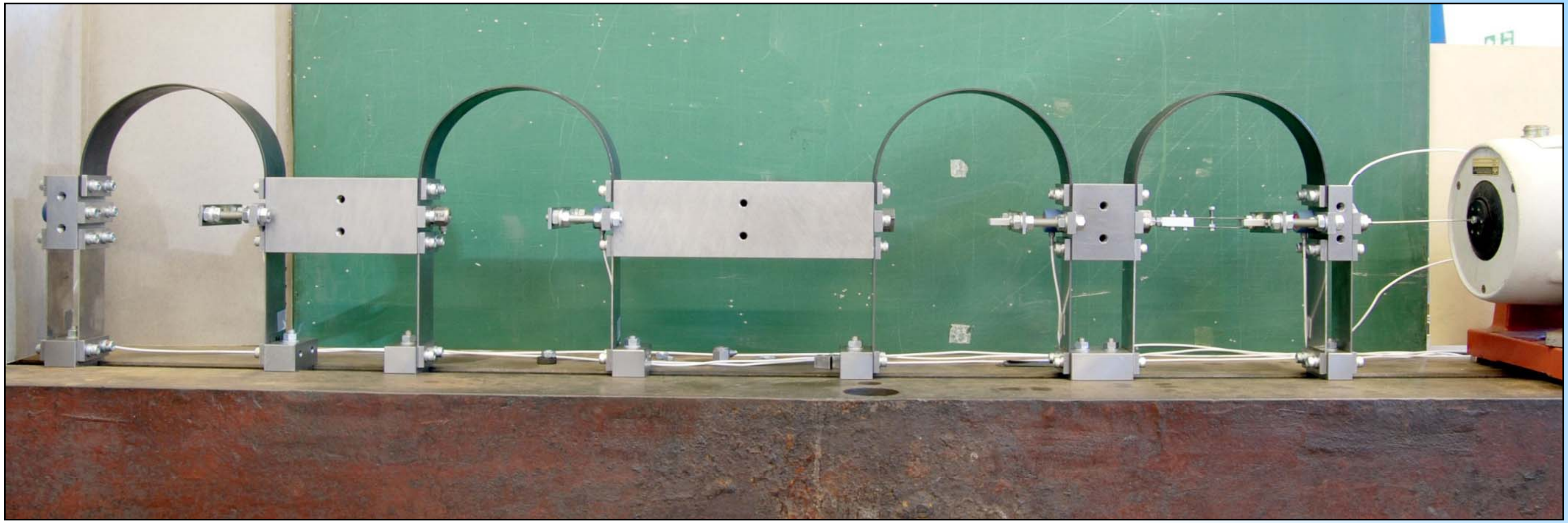
Experiment 2

5-mass system



Experiment 2

5-mass system



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Viscous dashpot (DOF 4-5)

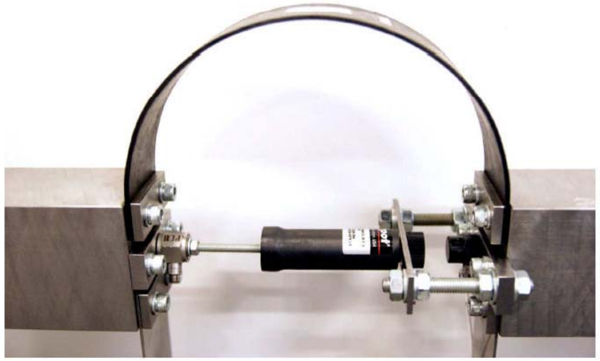


Figure 6.32: Viscous dashpot between DOFs 4 and 5

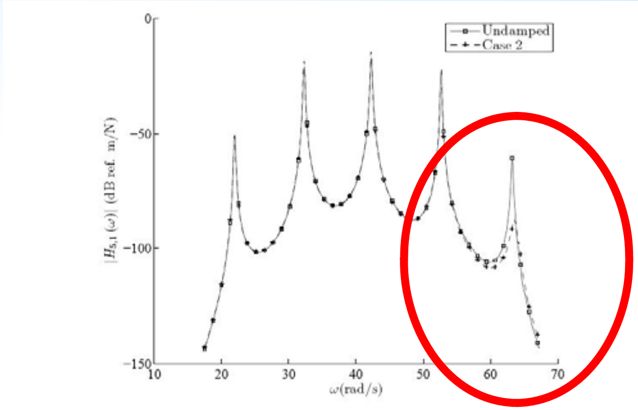
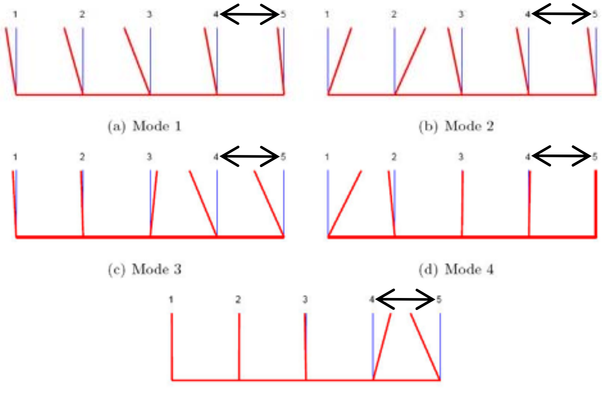


Figure 6.33: Experiment 2: FRF of the undamped system versus case 2



(a) Mode 1

(b) Mode 2

(c) Mode 3

(d) Mode 4

(e) Mode 5

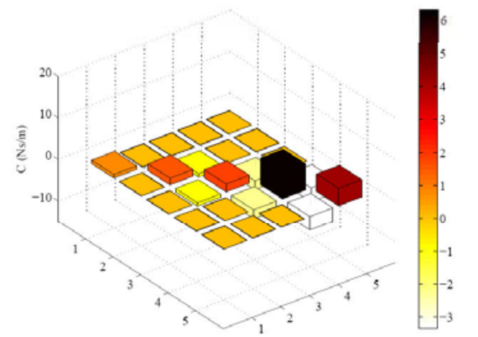


Figure 6.34: Identified damping matrix for case 2

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2 dashpots (DOF 2-3 and 4-5)

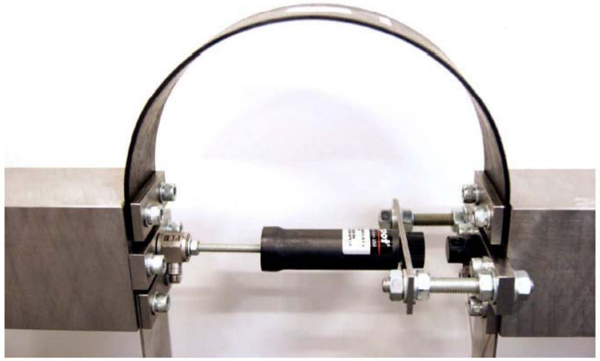
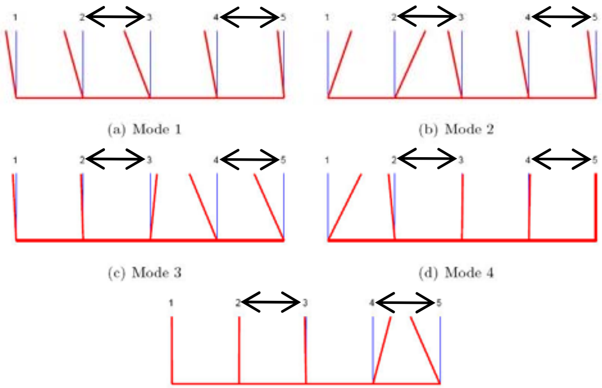


Figure 6.32: Viscous dashpot between DOFs 4 and 5



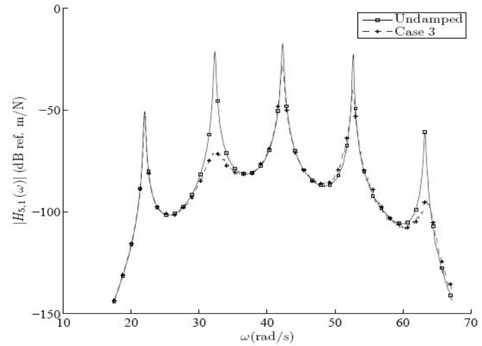


Figure 6.35: Experiment 2: FRF of the undamped system versus case 3

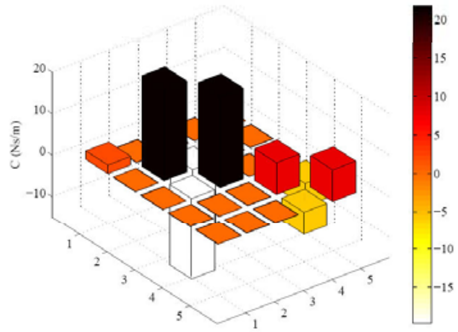


Figure 6.36: Identified damping matrix for case 3

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Viscous (DOF 3-4) Coulomb (2-3)

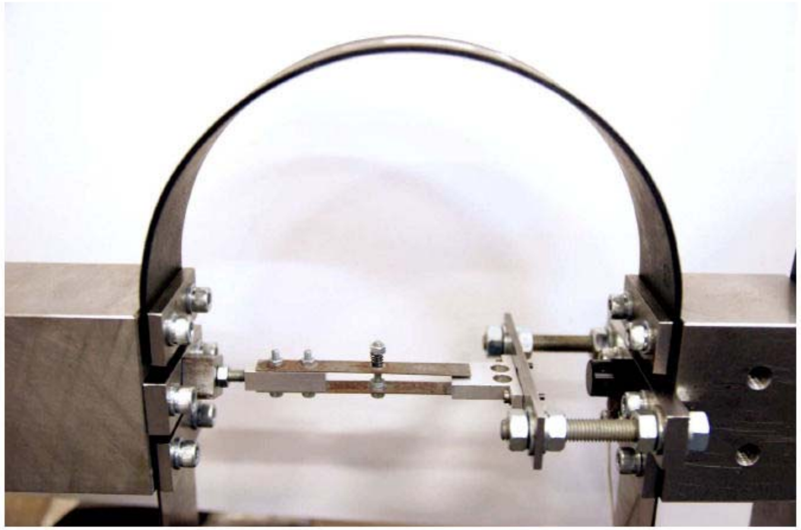

Figure 6.39: Coulomb friction device between DOFs 3 and 4

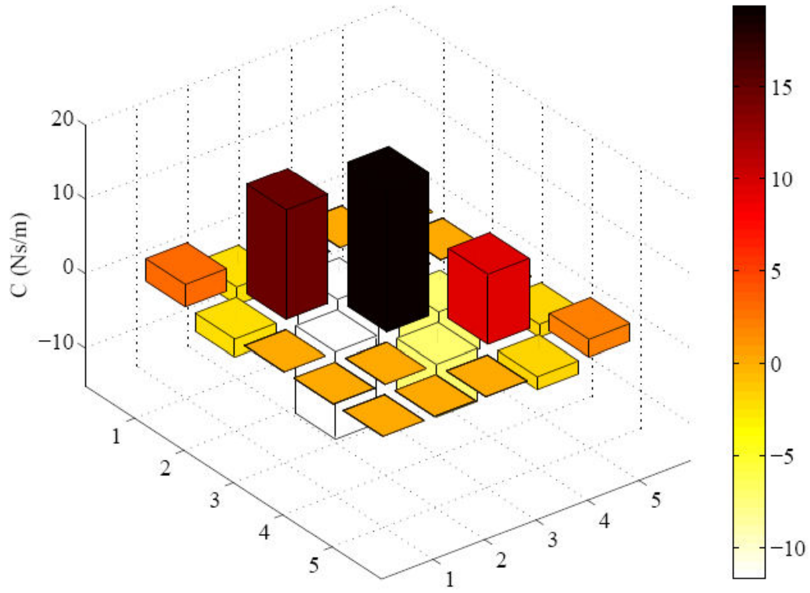

Figure 6.40: Identified damping matrix for case 4

Future work

- Further investigation on non-linear damping.

- Updating damping amplitudes by combining modal damping established methods.

- Damage or defect detection.

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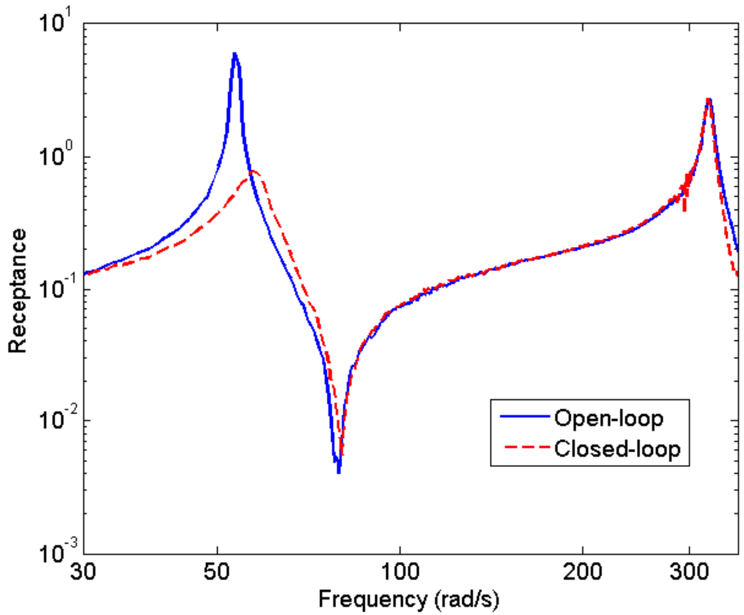
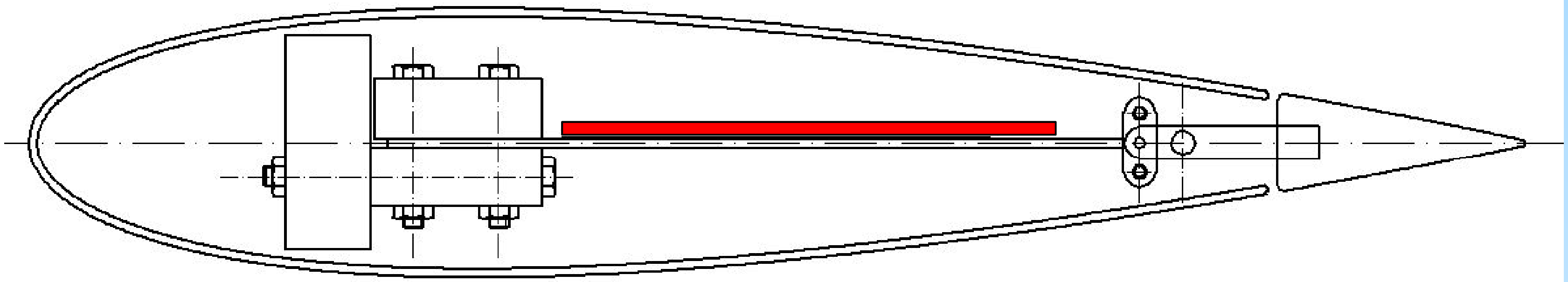
Current work

Receptance method in active vibration control of an aerofoil using piezoelectric actuators



Current work



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Acknowledgements

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- Dr Simon James
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Thank you

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