Research topics on flow-induced vibrations

PEF 6000 - Special topics on dynamics of structures

Associate Professor Guilherme R. Franzini

Objectives

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- To highlight the contributions from EPUSP to the state-of-art.

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- References: MsC dissertation written by Tatiana Ueno (2019), habilitation thesis written by Gonçalves (2013, Fujarra (2013), Rateiro (2014) and Franzini (2019) and selected papers.

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- Passive control;
- Flexible cylinder VIV;
- Concomitant excitation.

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- Examples of references: Gonçalves (2013), Fujarra (2013), Gonçalves et al (2015)...

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- Gonçalves et al (2016): Experimental investigation on the effects of round corners.

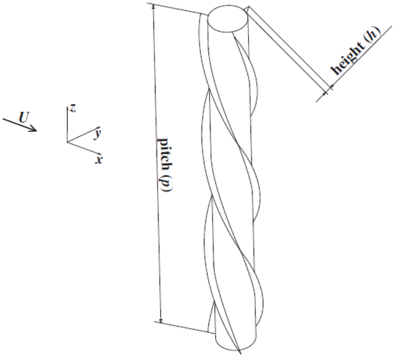

Figura: Extraído de Korkischko & Meneghini (2011).

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- Direct interference on the flow field.

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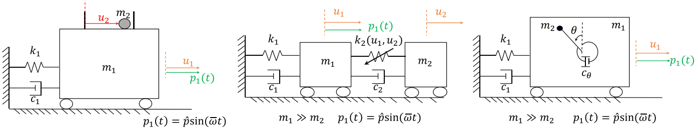

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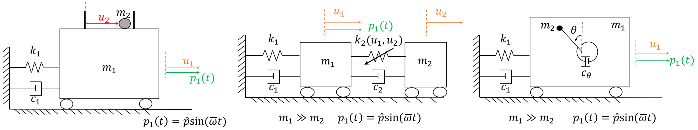

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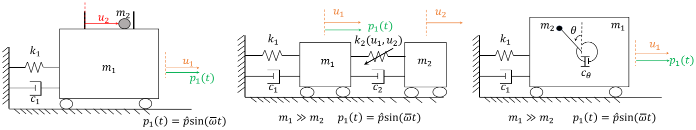

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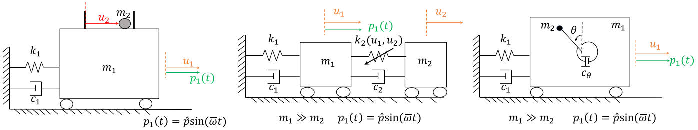

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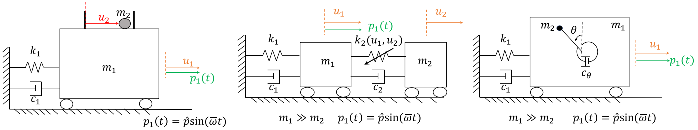

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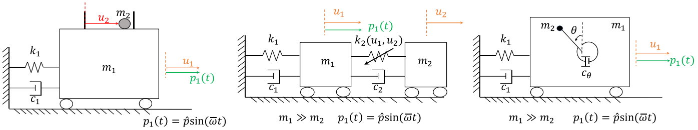

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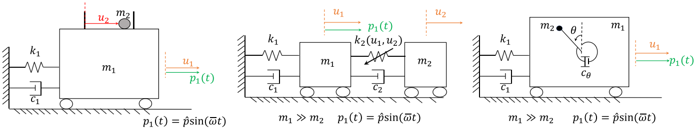

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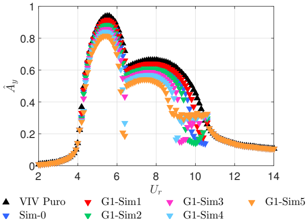
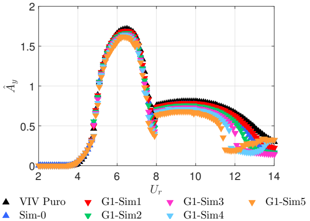
- On the other hand, wake-oscillators appear as an interesting alternative;
- The use of a rotative NVA is focus of the MsC. dissertation written by Ueno (2019) and the paper Ueno & Franzini (2019).
- At least to the best of the authors' knowledge, passive suppression of VIV-2dof using a rotative NVA was not found in the literature.

Passive suppression - Rotative NVA

- Results from Ueno (2019) and Ueno & Franzini (2019).
- Use of wake-oscillators allowed developing sensitivity studies with respect to the influence of the NVA on the suppression;
- In the following results: $\hat{r} = 0.50$ e $\zeta_\theta = 0.10$. G1-Sim1: $\hat{m} = 0.03$, G1-Sim2: $\hat{m} = 0.07$, G1-Sim3: $\hat{m} = 0.10$, G1-Sim4: $\hat{m} = 0.12$ and G1-Sim5: $\hat{m} = 0.15$.



(a) $\hat{A}_y(U_r)$. VIV-1dof.



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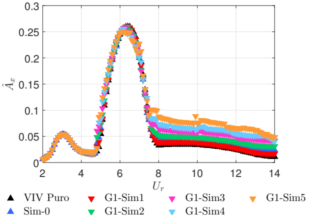
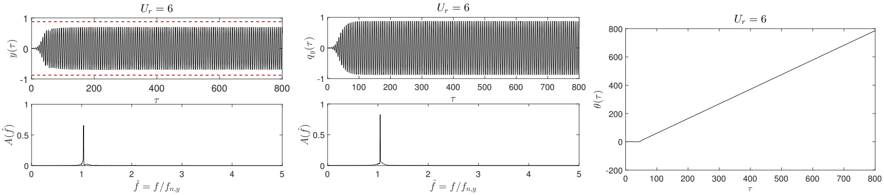


(c) $\hat{A}_x(U_r)$. VIV-2dof.

Extracted from Ueno (2019).

- Example of time-histories $\hat{r} = 0.50$, $\zeta_\theta = 0.10$, $\hat{m} = 0.15$ - $U_r = 6$. VIV-1dof.

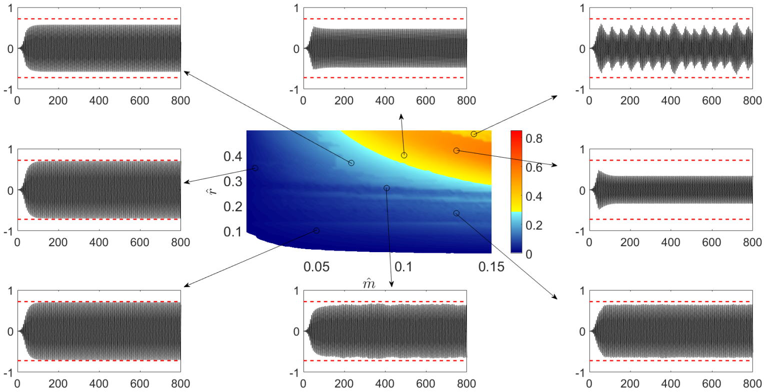


(a) $y(\tau)$ and amplitude spectrum. (b) $q_y(\tau)$ and amplitude spectrum. (c) $\theta(\tau)$.

- 1 : 1 : 1 resonance (TET mechanism).

Adapted from Ueno (2019).

- In the colorbar, the map above shows an efficiency criterion. Values close to 1 refer to high efficiency.



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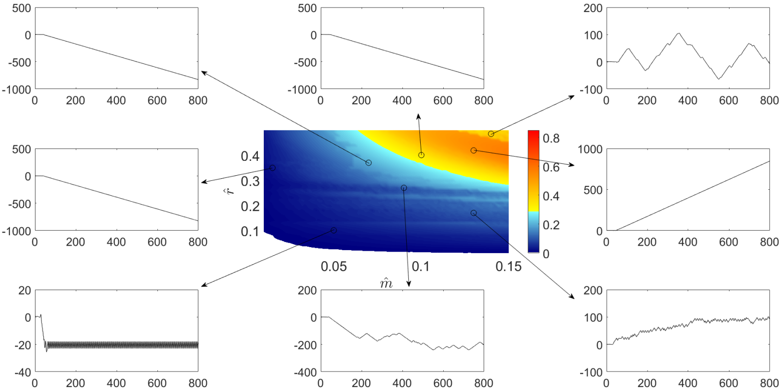

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- Already discussed: The response to VIV is intrinsically more intricate than that observed in rigid and elastically supported cylinders;

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- Possible alternative: "Quasi-Bessel" modes.
- Due to the non-linear character of the mathematical model, the system of ODEs will be coupled How to evaluate the number of adopted modes?

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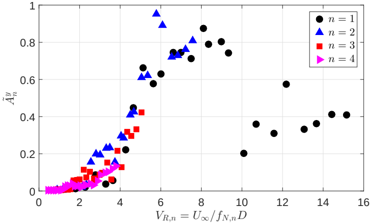
- A comprehensive research project on nonlinear dynamics of risers was developed at EPUSP and LMO led the experimental activities. This class brings experimental results from this project.

Modal-amplitude time-histories: vertical flexible cylinder

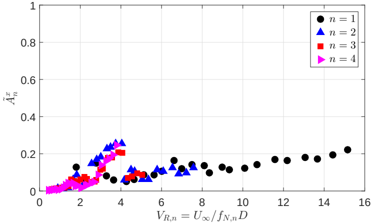
- Modal decomposition: Decompose the measured data into a set of projection functions. Allows identifying the participation of different modes in the response.

$$\tilde{a}_n^x(t_j) = \frac{\int_0^1 X^*(z,t_j)\psi_n(z)d\xi}{\int_0^1 (\psi_n(z))^2 d\xi} \quad (1)$$

$$\tilde{a}_n^y(t_j) = \frac{\int_0^1 Y^*(z,t_j)\psi_n(z)d\xi}{\int_0^1 (\psi_n(z))^2 d\xi} \quad (2)$$



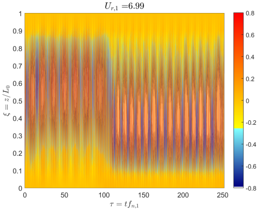
(a) Cross-wise characteristic modal-amplitude oscillation $\tilde{A}_n^y$.



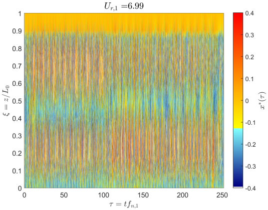
(b) In-line characteristic modal-amplitude oscillation $\tilde{A}_n^x$.

Extracted from Franzini et al (2016).

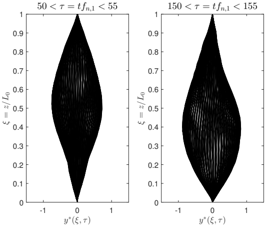
Different regimes may appear in the same nominal modal reduced velocity $U_{r,1} = U_\infty / f_{n,1} D$. The figure below is extracted from Franzini (2019).



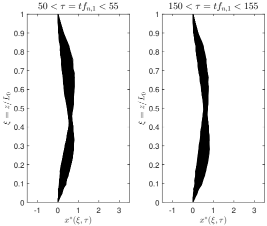
(a) Scalogram $y^*(\xi, \tau)$.



(b) Scalogram $x^*(\xi, \tau)$.

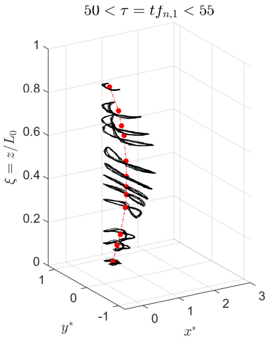


(c) Instantaneous deformed cross-wise configuration.

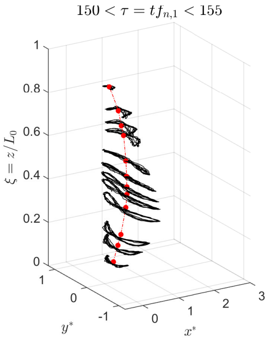


(d) Instantaneous deformed in-line configuration.

Trajectories on the horizontal plane.



(a) $50 < \tau < 55$.



(b) $150 < \tau < 155$.

Extracted from Franzini (2019).

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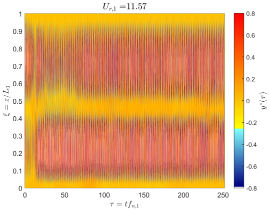
The figure below is extracted from Franzini (2019).



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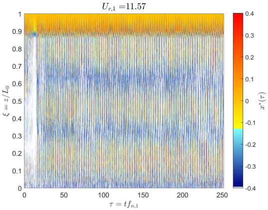
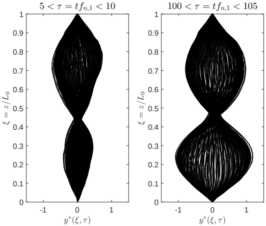


(b) Scalogram $x^*(\xi, \tau)$.



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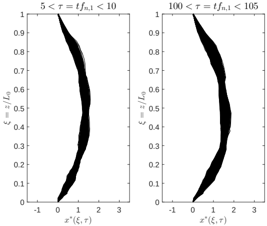

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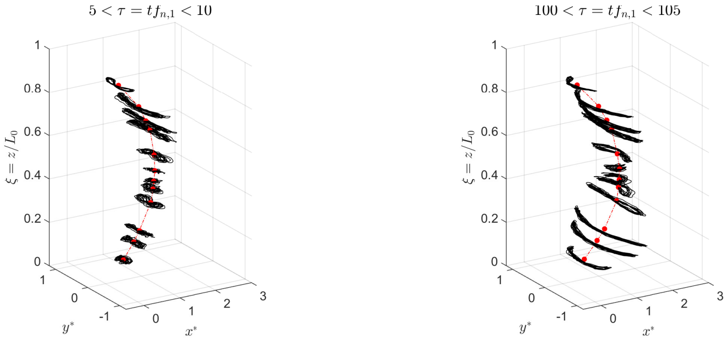

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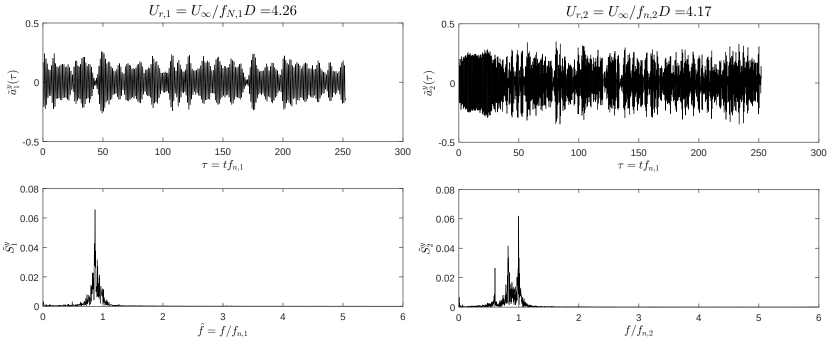
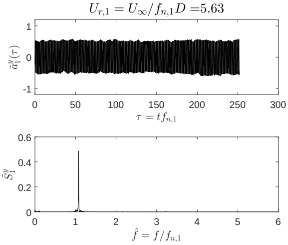
Extracted from Franzini (2019).

Analyses with modal-amplitude time-histories

- Modal-amplitude time-histories allow investigating the participation of each mode in the response. They contain information of all measured points. We illustrate two modal amplitude time-histories from different tests (different U_∞), but at similar modal reduced velocity $U_{r,k} = U_\infty / f_{n,k} D$. From free-decay tests, $f_{n,2} = 2f_{n,1}$, $f_{n,3} = 3f_{n,1}$



(a) $\tilde{a}_1^y(\tau)$ and amplitude spectrum. (b) $\tilde{a}_1^y(\tau)$ and amplitude spectrum.



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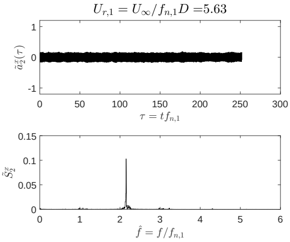
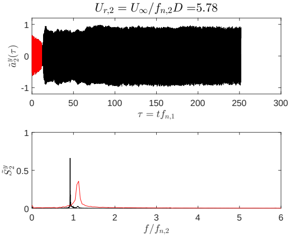
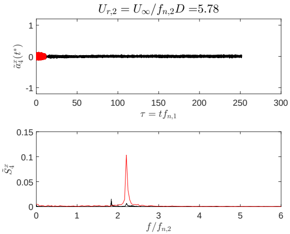


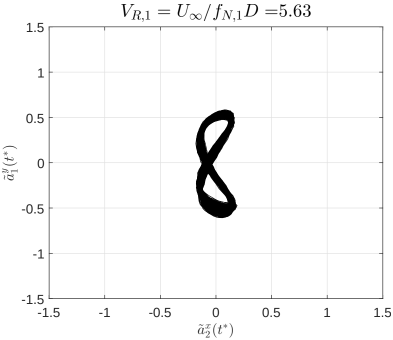
(b) $\tilde{a}_{\mathbf{2}}^x(\tau)$ and amplitude spectrum.



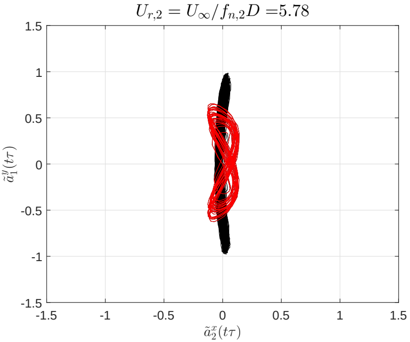
(c) $\tilde{a}_{\mathbf{2}}^y(\tau)$ and amplitude spectrum.



(d) $\tilde{a}_{\mathbf{4}}^x(\tau)$ and amplitude spectrum.

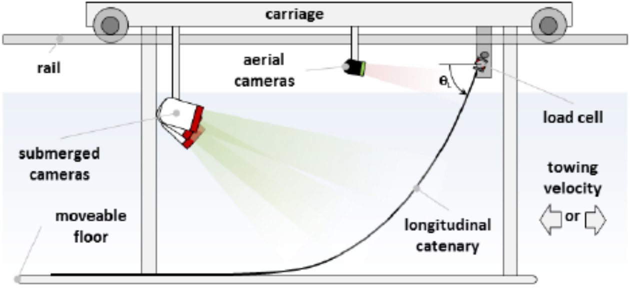


(a) $\tilde{a}_\mathbf{2}^x \times \tilde{a}_\mathbf{1}^y$. $U_{r,\mathbf{1}} = 5.63$.



(b) $\tilde{a}_\mathbf{4}^x \times \tilde{a}_\mathbf{2}^y$. $U_{r,\mathbf{2}} = 5.78$.

Extracted from Franzini (2019).



Extracted from Rateiro et al (2016).

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- Modal decomposition: Characteristic modal-amplitude *versus* modal reduced velocity exhibit good agreement in different modes.

In the offshore engineering scenario, problems involving VIV occur under combined excitation. Two cases are herein highlighted:

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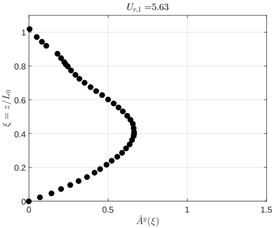
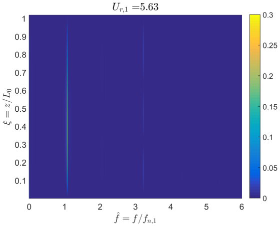
- At least to the best of the author's knowledge, experimental data concerning concomitant VIV and internal flow excitation are not found.

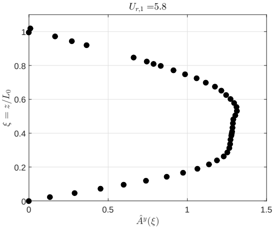
- Combined flexible cylinder VIV and parametric excitation: Experimental results published in Franzini (2018);
- This class focuses on the simultaneous VIV and parametric excitation with $f_t : f_{n,1} = 2:1$ and $A_t/L_0 = 1\%$. Figure below, adapted from Franzini (2018), illustrates the cross-wise envelope amplitude and the cross-wise amplitude spectra;
- The simultaneous VIV and parametric excitation with $f_t : f_{n,1} = 2:1$ (principal parametric instability in the first mode) significantly affects the response of the hydroelastic system;
- A marked increase in the oscillation amplitude is observed.



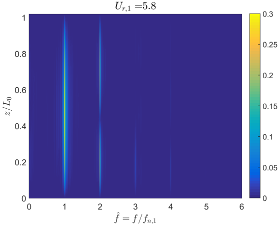
(a) $\hat{A}^y(\xi)$. "Pure VIV".



(b) $S_y(\xi, \hat{f})$. "Pure VIV".



(c) $\hat{A}^y(\xi)$. $f_t : f_{n,1} = 2 : 1$.

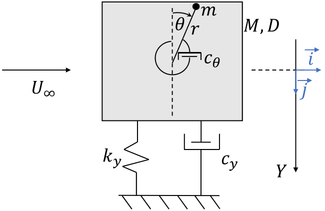


(d) $S_y(\xi, \hat{f})$. $f_t : f_{n,1} = 2 : 1$.

Adapted from Franzini et al (2018).

- Combined flexible cylinder VIV and excitation due to the internal flow is also an important and complex issue → Ongoing research topic developed at LMO;
- Usual approach: To consider wake-oscillator models with the same empirically calibrated parameters obtained for rigid and elastically mounted cylinders;
- Superposition of models associated with "pure VIV" and "pure" internal flow excitation;
- Experiments on this combined excitation are quite complex → Planed to be carried out by LMO (part of the PhD research developed by Wagner Defensor).
- In Orsino et al (2018), the numerical results show that there is a range of internal flow velocities associated with VIV mitigation.

- Focus on the galloping of a square prism, fitted with a rotative NVA;
- Studies developed by Bianca Teixeira (former undergraduate student) and presented in Teixeira et al (2018) and in Franzini (2019).
- Use of the quasi-steady hypothesis;



Extracted from Franzini (2019).

- Equations of motion

$$(M+m)\frac{d^2Y}{dt^2} + mr\left[\sin\theta\frac{d^2\theta}{dt^2} + \cos\theta\left(\frac{d\theta}{dt}\right)^2\right] + c_y\frac{dY}{dt} + k_yY = \frac{1}{2}\rho U_\infty^2 D C_y \quad (3)$$

$$mr^2\frac{d^2\theta}{dt^2} + mr\sin\theta\frac{d^2Y}{dt^2} + c_\theta\frac{d\theta}{dt} = 0 \quad (4)$$

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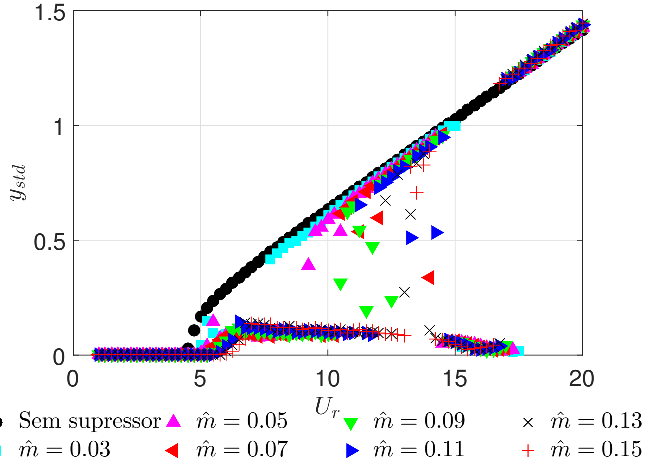
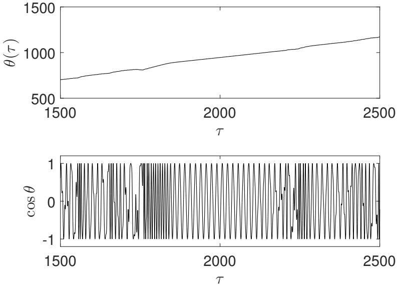
$\hat{r} = 0.40$, $\zeta_\theta = 0.05$, $\zeta_y = 0.0009$.

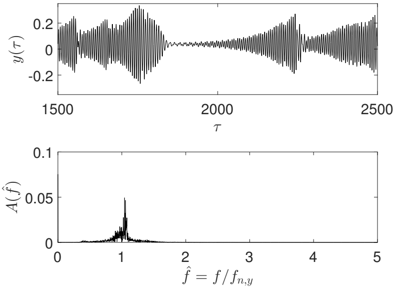


Extracted from Franzini (2019).

$U_r = 12$, $\hat{m} = 0.13$, $\hat{r} = 0.40$, $\zeta_\theta = 0.05$ and $\zeta_y = 0.0009$.



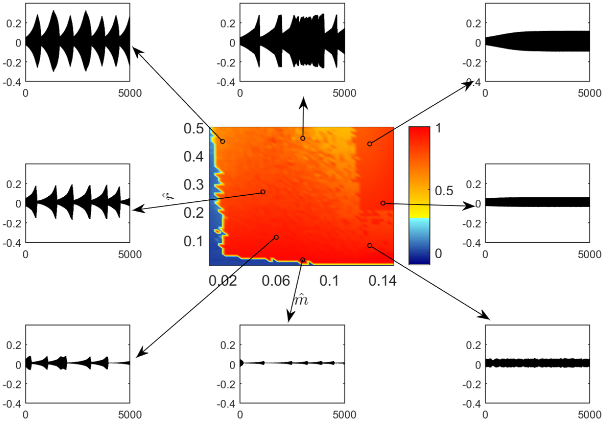
(a) $\theta(\tau)$ and $\cos\theta$.



(b) $y(\tau)$ and amplitude spectrum.

Extracted from Franzini (2019).

$\zeta_\theta = 0.05$ e $U_r = 6.5$. Standard-deviation of the response without suppressor is $y_{std,0} = 0.34$. $\hat{S} = 1 - \frac{y_{std,NVA}}{y_{std,0}}$.



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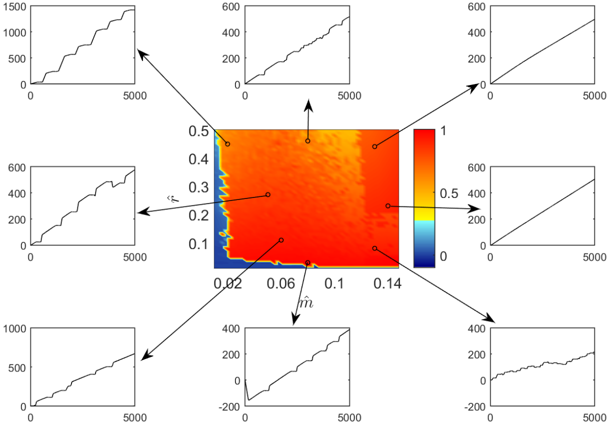
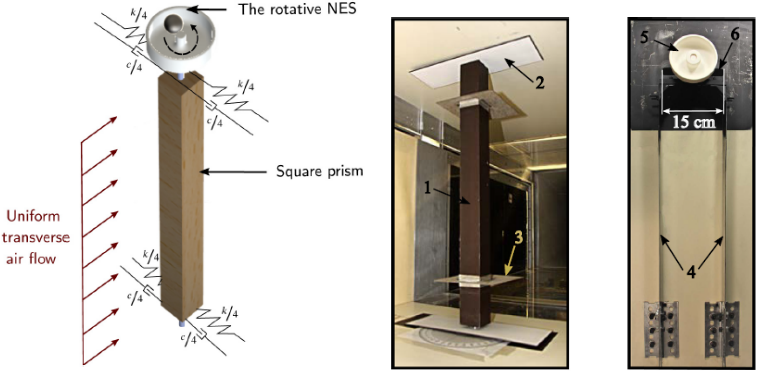


Extracted from Franzini (2019).

- Wind tunnel experiments carried out at École Polytechnique de Montréal;
- Balls constrained to move along circular tracks;
- Experiments carried out by Michael Selwanis (PhD candidate) and published in Selwanis et al (2021).



Extracted from Selwanis et al (2021).

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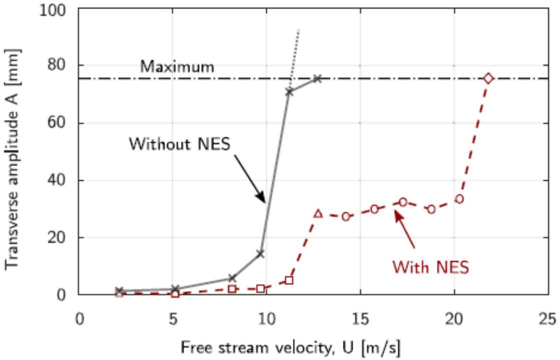
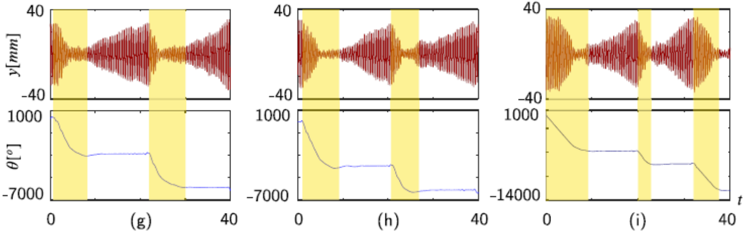
- The proposed suppressor has proved to be highly efficient!



Extracted from Selwanis et al (2021).

- Some features of the response numerically observed appear in the experiments



Extracted from Selwanis et al (2021).

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- In the dynamics of catenary risers: Motion prescribed to the top+parametric excitation+VIV+internal flow effects=?.

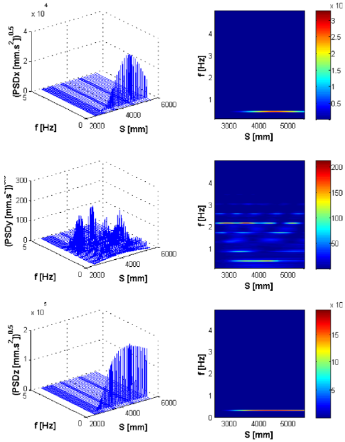

Figure 16. Energy spectra along riser; $2\pi\frac{A_i}{D} = 30$; f_i=0.43Hz; f_i/f_1=1.

Extracted from Pesce et al (2017).

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- Different ways for converting energy: Gravitational potential energy, electromagnetic conversion, piezoelectric conversion;
- Focus on low-power systems (small sensors, for example).

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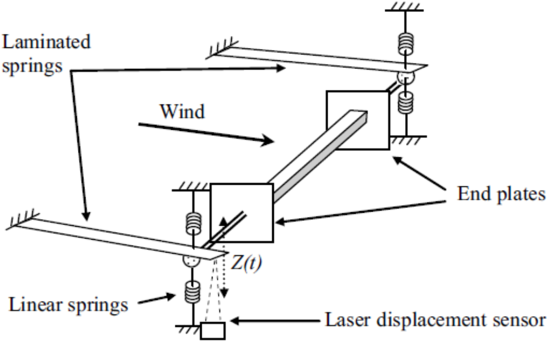
- Franzini et al (2016,2017): Concomitant parametric excitation and galloping increases the harvested power in piezoelectric circuits.

Magnets are placed at the tip of the leaves-springs and can move relative to coils.



Extracted from Hémon et al (2017).

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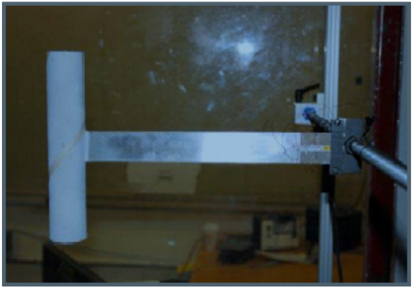
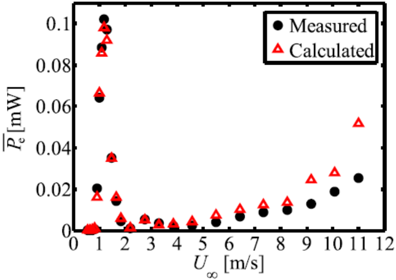
- Madi et al (2019): Developed by Leticia Madi (PhD candidate), this paper deals with piezoelectric energy harvesting from flexible cylinder VIV.

Piezoelectric patches are included at the clamp.



(e) Experimental arrangement.

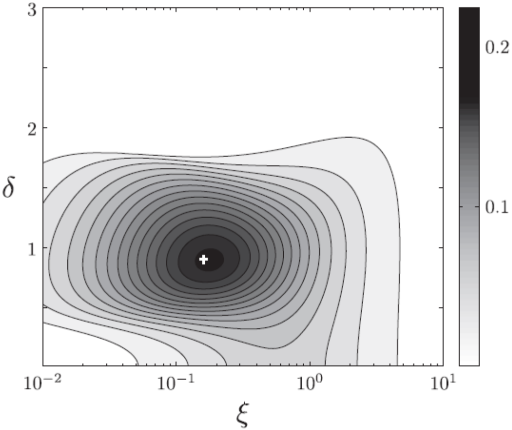


(f) Electrical power.

Extracted from Akaydin et al (2012).

Result from Grouthier et al (2014)

Existence of a critical structural damping ratio ξ for maximizing energy harvesting efficiency.



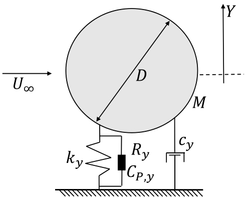
Extracted from Grouthier et al (2014).

- The rigid cylinder is assembled onto a piezoelectric support. The electrical circuit is characterized by its capacitance $C_{P,y}$ and resistance R_y. θ_y is the electromechanical coupling term.
- For the VIV-1dof condition, the solid-fluid-electric system is governed by:

$$(M + m_a^{pot})\frac{d^2Y}{dt^2} + c_y\frac{dY}{dt} + k_yY - \theta_yV_y = \frac{1}{2}\rho U_\infty^2 DLC_{y,v} \quad (5)$$

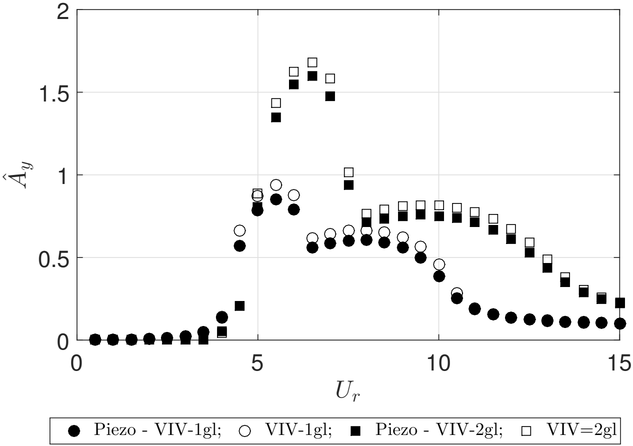
$$\frac{d^2q_y}{dt^2} + \epsilon_y\omega_f(q_y^2 - 1)\frac{dq_y}{dt} + \omega_f^2 q_y = \frac{A_y}{D}\frac{d^2Y}{dt^2} \quad (6)$$

$$C_{P,y}\frac{dV_y}{dt} + \frac{V_y}{R_y} + \theta_y\frac{dY}{dt} = 0 \quad (7)$$



Extracted from Franzini & Bunzel (2018).

- Due to energy harvesting, a small decrease in the cylinder response.



Adapted from Franzini & Bunzel (2018).

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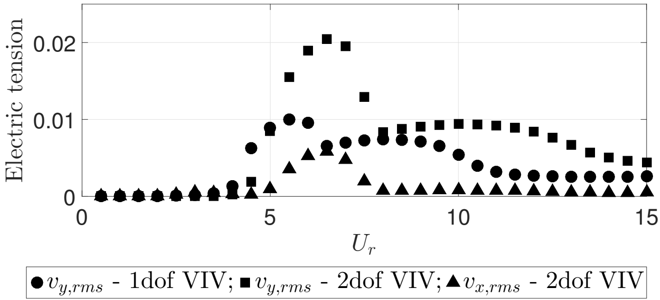
- Energy harvesting is more efficient if the cylinder is assembled onto a 2dof elastic support.



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