Maximization of the electrical power generated by a piezo-magneto-elastic energy harvesting device

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Energy harvesting

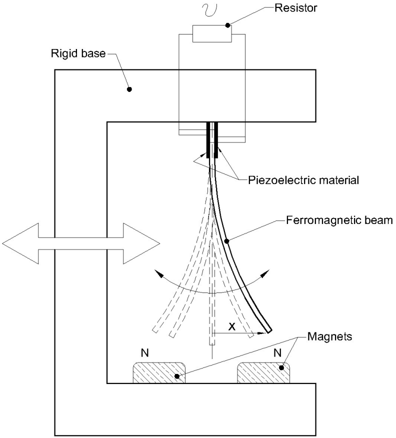
The idea of harvesting:

- Capture energy from external sources, as vibration and pressure differences
- Support small electrical and electronic embarked equipment
- Support small electrical circuits in hazard areas
- Supply small electrical demand for remotely placed equipment

Objectives

- Investigate the full nonlinear device behavior (time series, phase space trajectories, Poincaré maps and ressonance curves)
- Solve optimization power, by finding parameters' values which maximize device's output power

Physical system of interest



A. Erturk, J. Hoffmann and D. J. Inman, *A piezomagnetoelastic structure for broadband vibration energy harvesting*. **Applied Physics Letters**, 94: 254102, 2009.

Mathematical model

- For mechanical behavior:

$$\ddot{x} + 2\xi\dot{x} - \frac{1}{2}x(1 - x^2) - \chi v = f\cos\Omega t$$

- For electrical behavior:

$$\dot{v} + \lambda v + \kappa\dot{x} = 0$$

- Initial conditions:

$$x(0) = x_0,\ \dot{x}(0) = \dot{x}_0,\ v(0) = v_0$$

- Runge-Kutta integration scheme is used to solve the IPV

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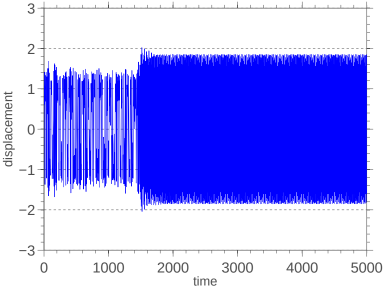
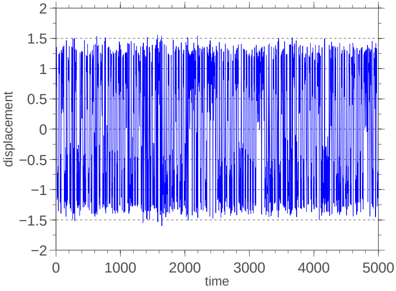
Displacement time series

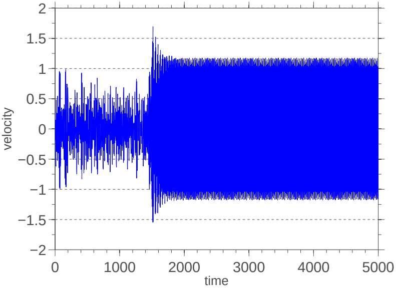


(a) f = 0.12



(b) f = 0.10

Velocity time series



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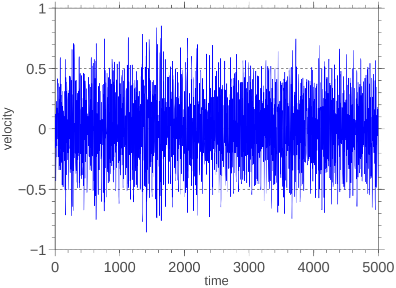

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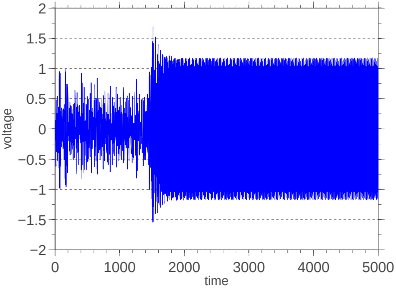
Voltage time series



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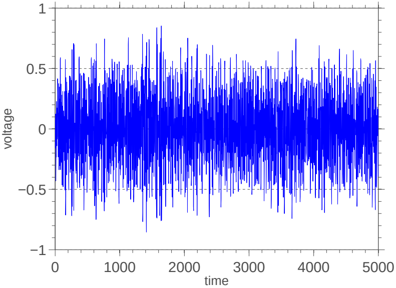
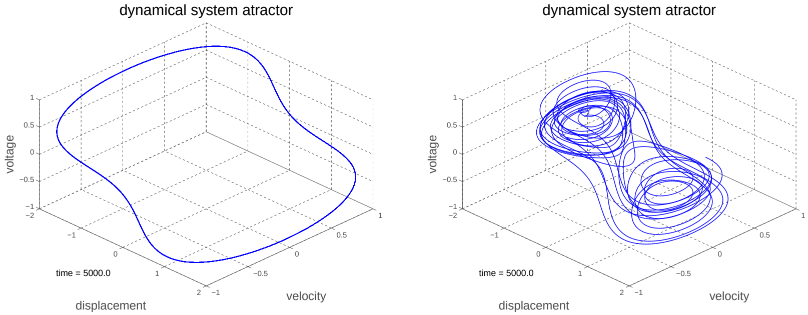


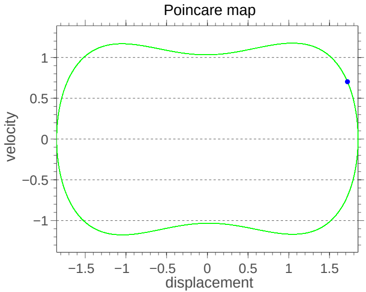
(b) f = 0.10

Atractors in phase space



(a) f = 0.12 (b) f = 0.10

Poincaré maps



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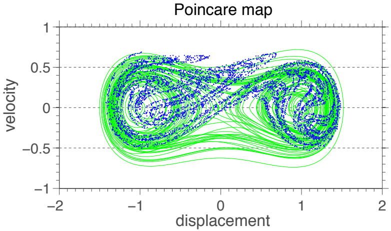
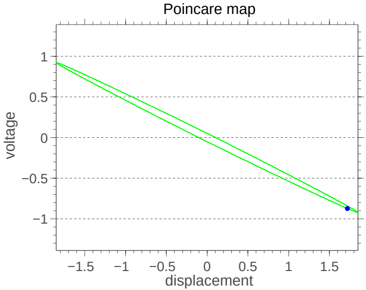


(b) f = 0.10

Poincaré maps



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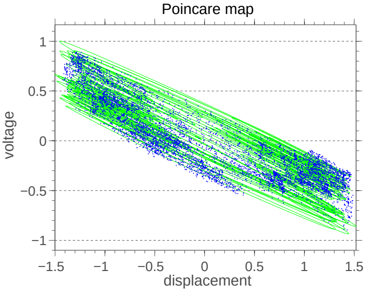

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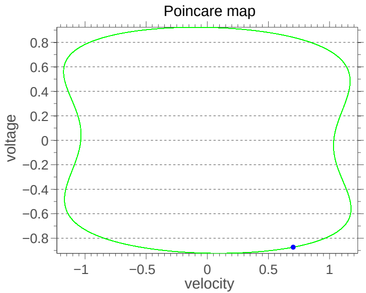
Poincaré maps



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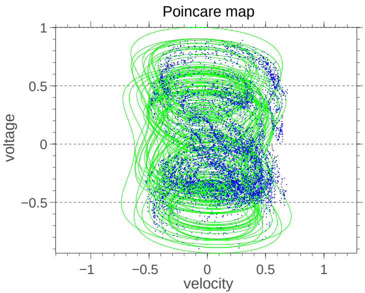
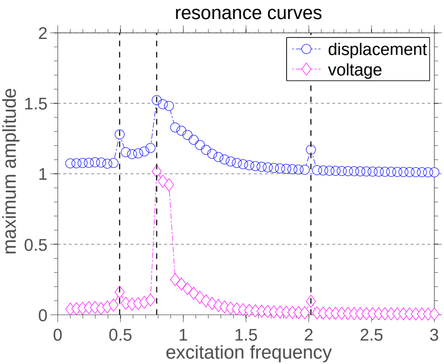


(b) f = 0.10

Ressonance curves



0-1 test for chaos: receipt

Given a time series $(x_1, \cdots, x_N)$, for several $c \in (0, \pi)$:

1. change from coordinates $(x, \dot{x})$ to (p, q):

   $p(n) = \sum_{j=1}^{n} x_j \cos(j\,c), \quad q(n) = \sum_{j=1}^{n} x_j \sin(j\,c)$

2. compute mean square displacement (for $0 \ll n \ll N$):

   $M(n) = \frac{1}{N} \sum_{j=1}^{N} \left([p(j+n) - p(j)]^2 + [q(j+n) - q(j)]^2 \right)$

3. compute correlation:

   $K_c = \texttt{corr}\left\{(1, 2, \cdots, n), (M(1), M(2), \cdots, M(n))\right\}$

4. compute median:

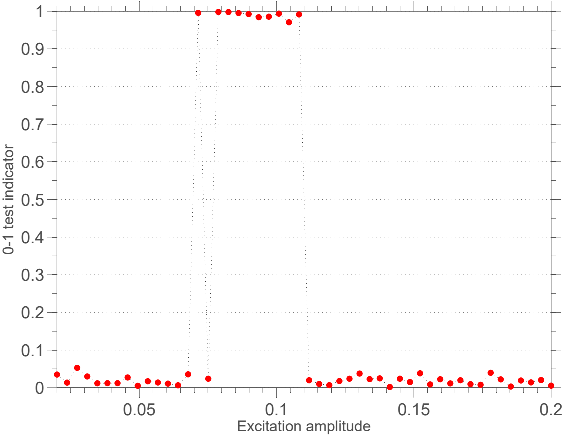
   $K = \texttt{median}\left\{K_c\right\}$

Numerical indicator $K \in \{0, 1\}$:

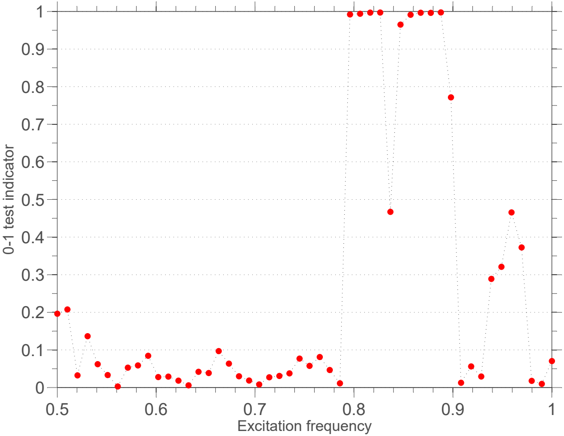
$K = 0$: regular dynamics

$K = 1$: chaotic dynamics

0-1 test for chaos: analysis



0-1 test for chaos: analysis



Optimization of recovered power

Find a pair (x_0, f) which maximize

$$\langle \mathcal{P} \rangle = \frac{1}{\tau} \int_{t}^{t+\tau} v^2(t')\, dt'$$

(mean power)

such that

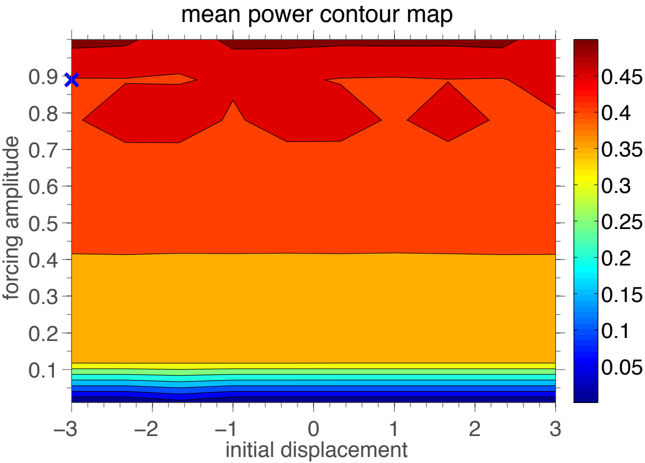
$$K = 0.$$

(system dynamics is regular, i.e., not chaotic)

Solution strategy

- A grid (x_0, f) is discretized
- The equations are integrated for each point
- The 0-1 test for chaos is applied to identify non-chaotic results
- Compute the mean power of those regular results and compare them

Mean power contour map



Final remarks

Contributions:

- Investigation of a harvesting device nonlinear behavior
- Solution of an optimization problem to increase recovered power

Future objectives:

- Investigate the influence of other parameters over device's dynamics and optimization power problem results
- Refine solution strategy, by applying aleatory search methods

Acknowledgments

Enlightening comments about harvesting:

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Thank you for your attention!

joao.peterson@hotmail.com

J. V. L. L. Peterson, V. G. Lopes and A. Cunha Jr, *Numerically exploring the nonlinear dynamics of a piezo-magneto-elastic energy harvesting device.* **(in preparation)**.

Simulation Parameters

Parameters

parameter	value
ξ	0.01
χ	0.05
f	0.083
Ω	0.8
λ	0.05
κ	0.5
x_0	1.0
$\dot{x}_0$	0.0
v_0	0.0