Characterization and optimization of a 2DOF velocity amplified EM-EH

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Outline

1. The harvester
2. Characterization through transfer functions of the inner mass system
   - Sine sweep of increasing frequency data
   - Comparison with decreasing frequency: hysteresis
3. Same analysis for the whole system
4. Optimization Process
   - Configuration
   - Output voltage and power comparison at each acceleration
The Harvester

- Two masses system: collisions between the inner small mass, and the outer bigger one, provide velocity amplification.

- A coil is embedded in the inner mass. It is oscillating between two sets of magnets providing a strong magnetic field in the area.

\[ e.m.f. = -\frac{\partial \phi}{\partial t} \]

- The presence of two masses enlarges the bandwidth of the system, along with the periodic disconnection of the two masses from the springs.
Characterization: the transfer function

Let \( x(t) \) be the input and \( y(t) \) be the output of our system

\[
X(s) = \int_{-\infty}^{\infty} x(t)e^{-st} \, dt
\]

\[
Y(s) = \int_{-\infty}^{\infty} y(t)e^{-st} \, dt
\]

\[
H(s) = \frac{Y(s)}{X(s)}
\]

The Laplace transform is the Fourier transform when \( s = j\omega \)

\( H(s) \) is the TF only for linear systems: in nonlinear systems \( H(x(t),\omega) \). So, calculating the TF at different amplitudes of input, can show if the system is linear.
Constant acceleration input

Fourier Transform of the acceleration input

Frequency [Hz]

Fourier Transform [m/s²/s]
Constant acceleration input

Fourier Transform of the Voltage Output

Fourier Transform [V*s]

Frequency [Hz]
Nonlinearity through TF: shifting

The stiffness “decreases” interesting for small devices!
The hysteresis phenomenon

Frequency response of ideal harmonic oscillator
Nonlinearity through TF: hysteresis
Nonlinearity through TF: hysteresis
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Nonlinearity through TF: hysteresis

Transfer functions $a=0.2g$

- Decreasing Sine Sweep
- Increasing Sine Sweep

Frequency [Hz]
Nonlinearity through TF: hysteresis
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Characterization of the whole system: TFs
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Transfer functions at different accelerations

- $a=0.1g$
- $a=0.2g$
- $a=0.3g$
- $a=0.4g$
- $a=0.5g$

Frequency [Hz]
Characterization of the whole system: TFs

Transfer functions at different accelerations

Frequency [Hz]

TF
Characterization of the whole system: TFs

Transfer functions at different accelerations

Frequency [Hz]

TF

Vibrating Base

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Characterization of the whole system: TFs
Hysteresis
Optimization process

- Magnets 1/2 x 1/2 x 1/8 inches
- Coils of fixed volume r=9mm h=8mm
  - Wire diameter d=280um
  - Wire diameter d=170um
  - Wire diameter d=100um
- Outer mass steady
- For each coil the optimal resistance load has been found
- Comparison between output voltage and power for different coils at the same amplitude acceleration input
Load Resistance

Wire d=100um

Same analysis for each coil
Power Optimization
Acceleration $a=0.2g$
Power Optimization

Graphs showing power optimization across different frequencies.
Power Optimization

Acceleration $a=0.4g$
Power Optimization
Power Optimization

Acceleration $a=0.6g$
Conclusions and Wish List

✓ Study and interpretation of the TFs:
  ✓ At very little acceleration the system in basically linear, but early it becomes (also for the little mass alone) nonlinear
  ✓ We can think about miniaturize this system even if the linear resonance frequency increases, using the nonlinear shifting
✓ The coil with the 170um diameter wire seems to be the best for maximizing the power output with this set of magnets

➢ Find the best configuration for the magnets
➢ Miniaturization
Thank you for your attention.... Questions?