Robust vibration energy harvesting from nonlinear mechanisms

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Challenge

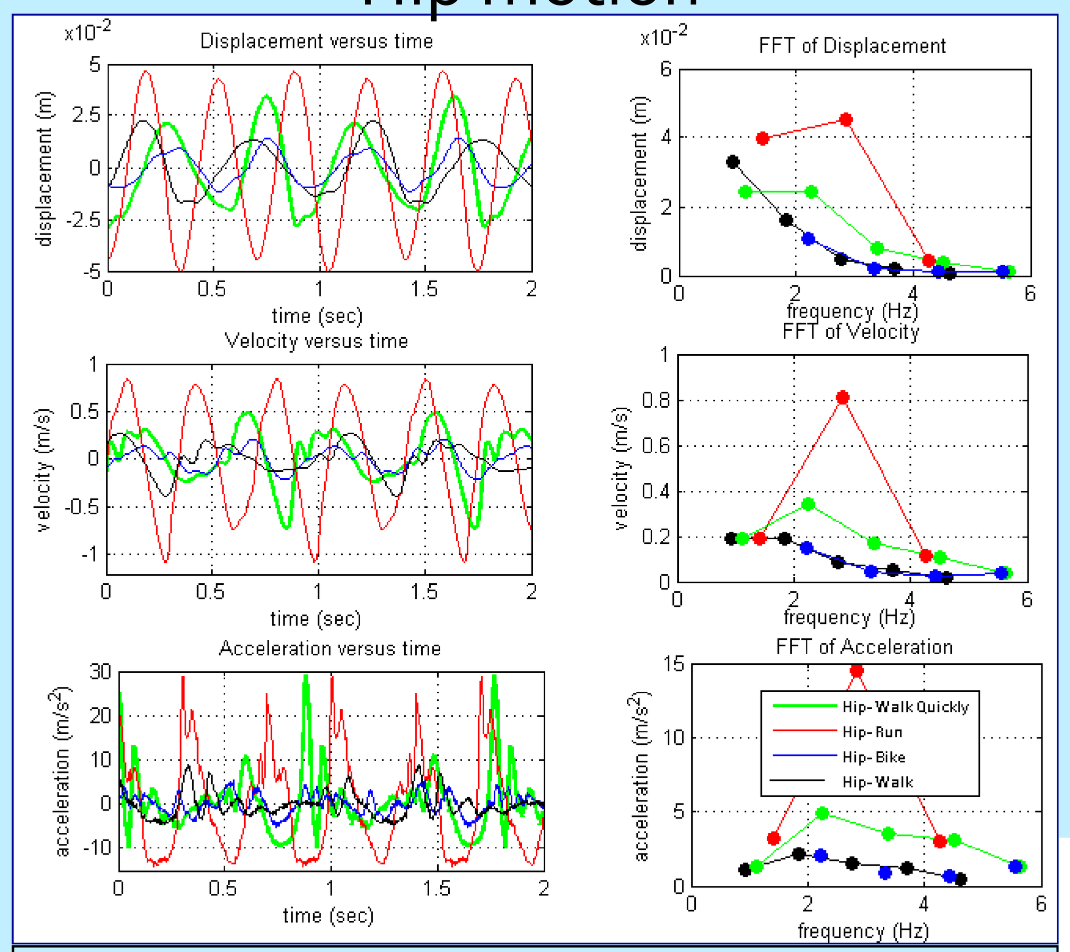
- Ambient vibrations are stochastic, multi-frequency, and time-varying
- Traditional linear oscillators can only absorb ambient energy at one frequency
- Example scenarios:
  - Ambient vibration energy harvesting
    - Cell phones carried by people
    - Ocean wave utility-scale generators
    - Small electronics in remote locations
    - MEMs sensors implanted in the body
  - Shock absorption
    - Protect offshore platforms from water wave impacts
    - Protect buildings from earthquakes

Solution

- Nonlinear oscillators are more robust to vibration signal changes than linear systems
  - Passive solution (versus using controls)

Case Study: Power a cell phone from a person walking

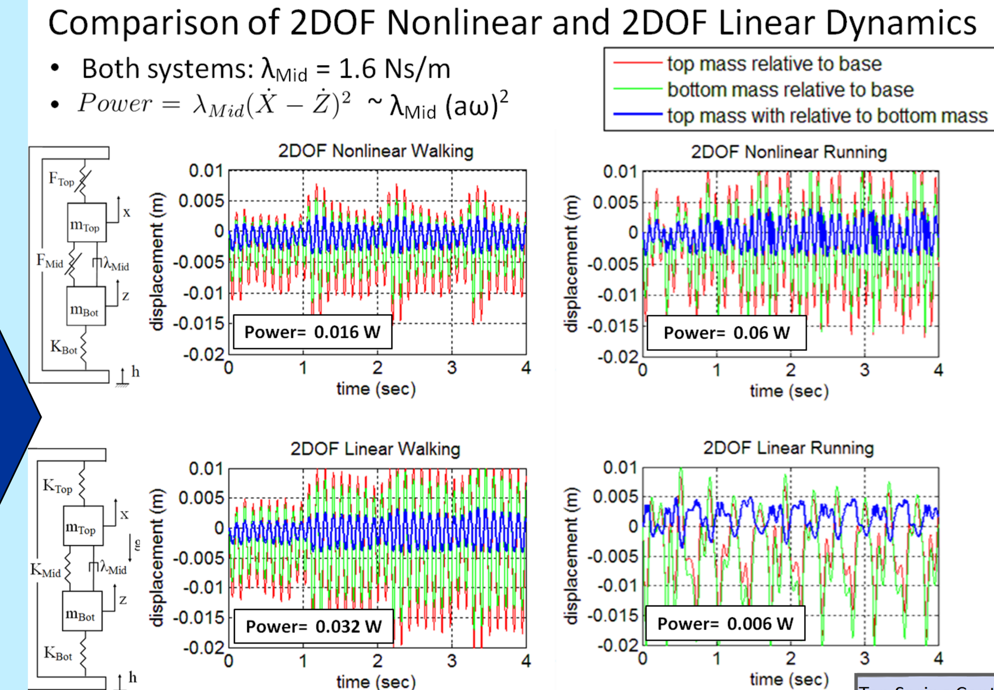
Hip motion



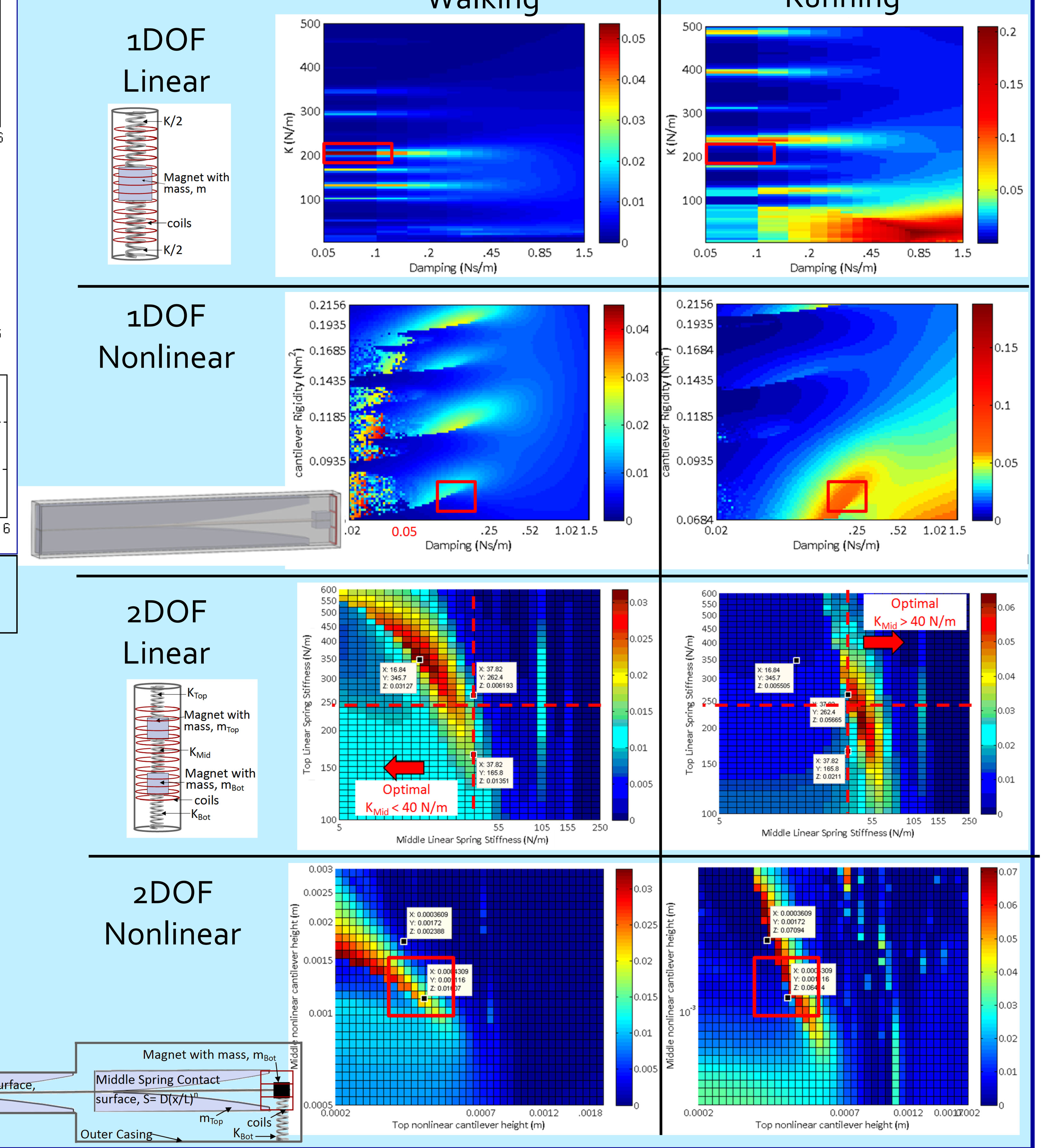
Experimentally recorded hip motions.
— Walk. — Walk quickly. — Run. — Bike.

Comparison of 2DOF Nonlinear and 2DOF Linear Dynamics

- Both systems: λ_{Mid} = 1.6 Ns/m
- $Power = \lambda_{Mid}(\dot{X}-\dot{Z})^2 \sim \lambda_{Mid}\,(a\omega)^2$



Power for varied parameters

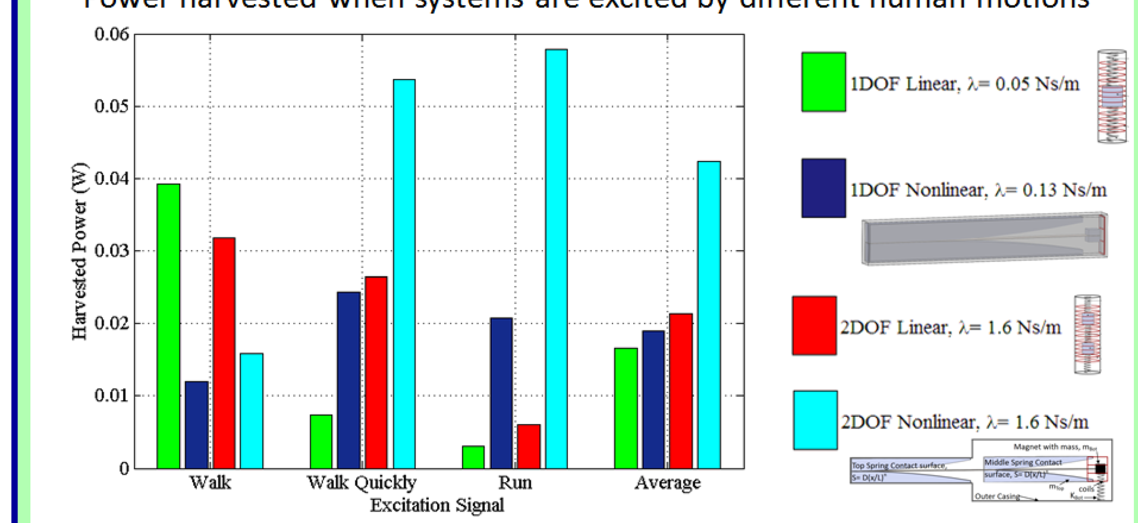


Conclusions

- Nonlinearity makes the system more robust to environmental vibration spectrum changes

System performance comparison

Power harvested when systems are excited by different human motions



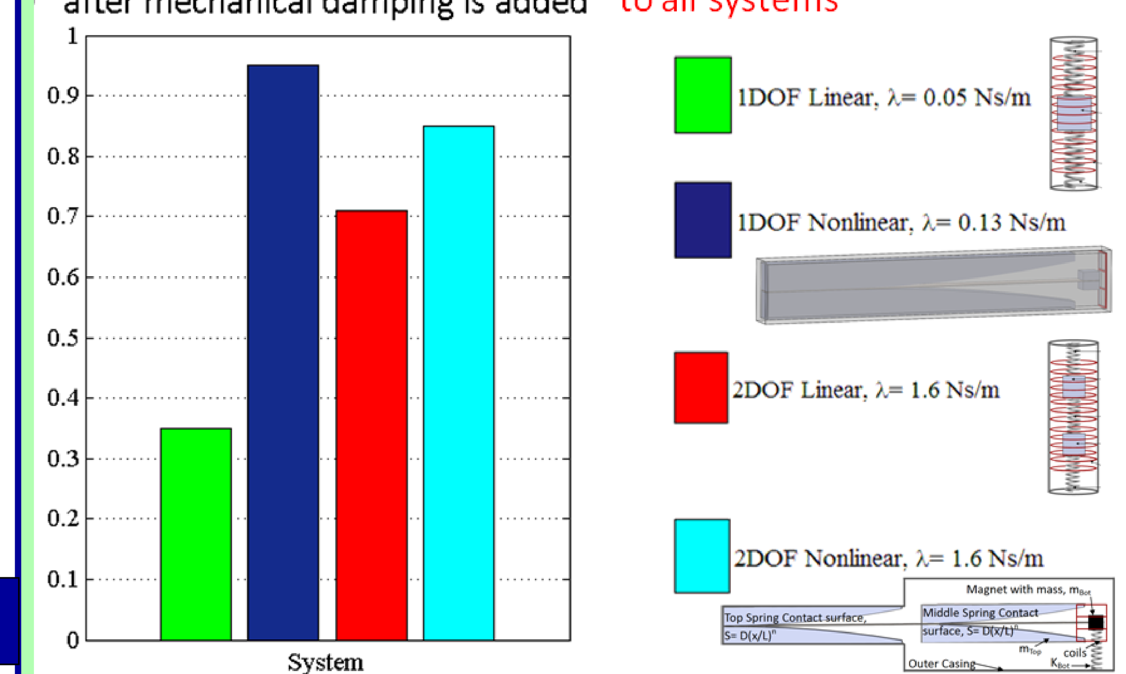
Common constraints:
- Total mass: 60 g
- Total device height: 6.8 cm
- Systems optimized for maximum average power
  - Constraint: non-negligible amount of harvested power during walking

- Nonlinear systems are also more robust to parasitic damping

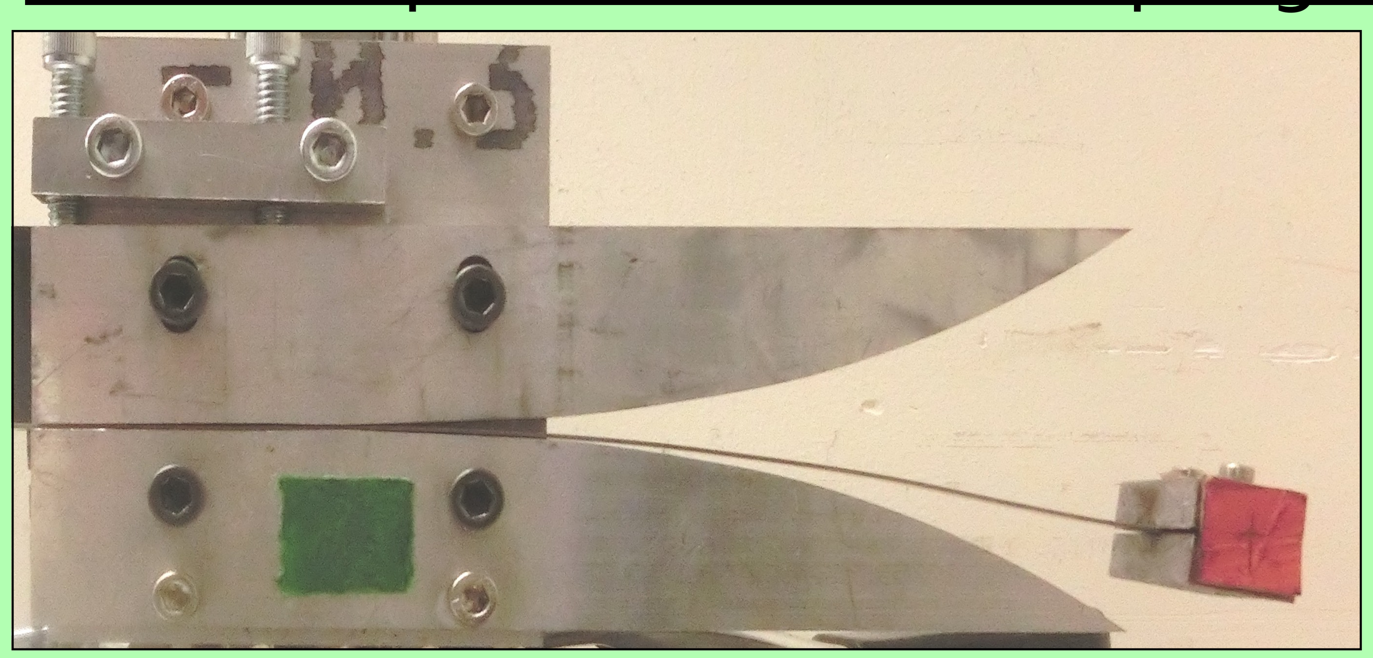
Robustness to Parasitic Damping

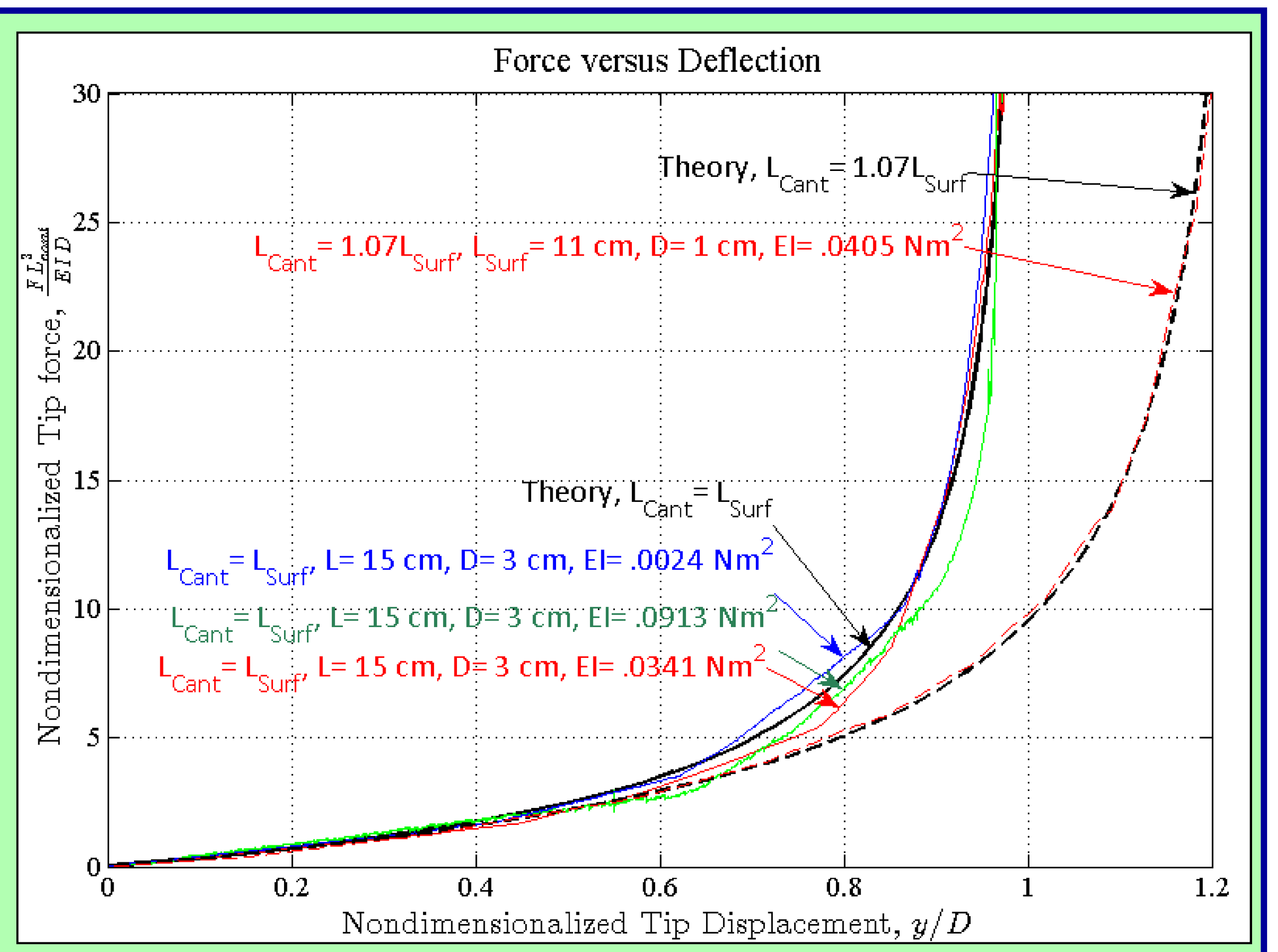
Fraction of power harvested after mechanical damping is added

Added λ_{Mech}= 0.06 Ns/m to all systems



How to implement nonlinear springs?

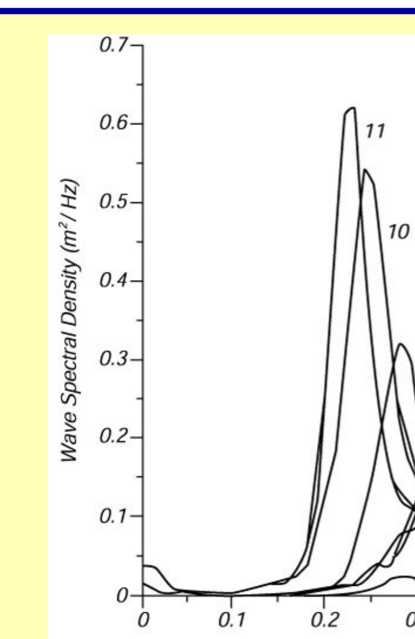




- A design with essential nonlinearity, low-friction, and one moving part (which increases device lifetime)

Future Work

- Build and test full prototypes with electromagnetic system
- Modify contact-surface stiffening-spring effect to be more volume-compact
- Analytically study stochastic nonlinear dynamics to predict maximum power and robustness
- Apply concepts to utility-scale ocean-wave electricity generation



Wave spectra of a developing sea for different fetches according to Hasselmann *et al.*, (1973).