Analysis, Design and Control of a new Generation of Compliant Actuators for Safe HRI

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Introduction

Compliance

- Safety **FIXED/VARIABLE**
  - "Soft" collisions
  - Decouple link from the actuator

- Performance/Energy efficiency
  - Energy exchange/conversion
  - Potential energy exploitation
  - Stiffness variation

VARIABLE

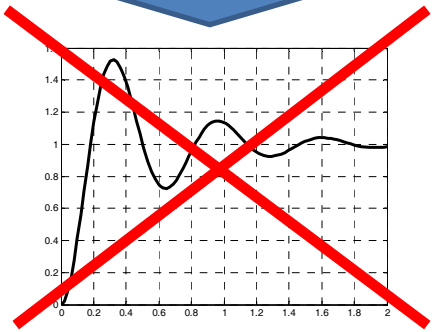
Introduction

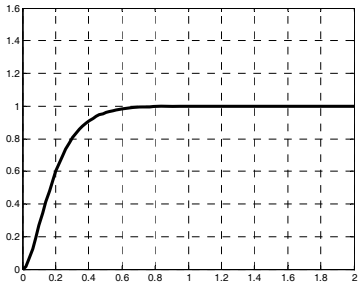
Compliance

- PROS
  - Safety
  - Performance
  - Energy efficiency
- CONS
  - Precision
  - Bandwidth
  - Complexity, volume, weight
  - Oscillations

    (TO BE DAMPED)

VARIABLE STIFFNESS





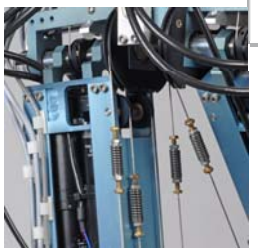
State of the art

COMPLIANCE

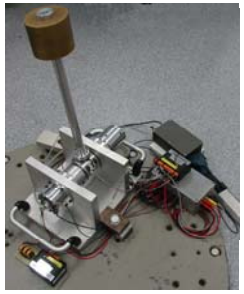
- **SEAs**
  - **Fixed (passive)**
  - **Variable (control)**
- **VSAs**
  - **Variable (passive)**

Pratt, Williamson, '95

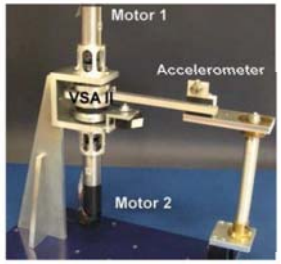
Tsagarakis, Laffranchi, et al, '09



Wisse et al, 2007



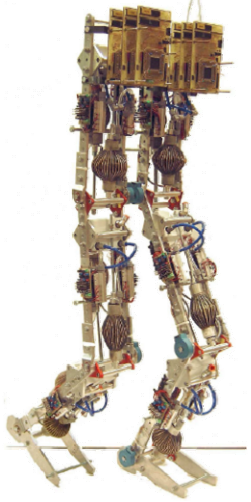
Wolf et al, 2008



Schiavi, Bicchi, 2008

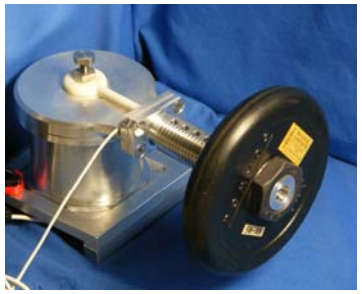
Van Ham et al, 2007

Verrelst et al, '05



DAMPING

- **VPDA**
  - **Variable (passive)**



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A Variable Physical Damping Actuator (VPDA) for Compliant Robotic Joints, TuF2.3

Development phases

1. **Preliminary analysis**

   Define a suitable configuration

   - task
   - stiffness range
   - dimension/weight
   - …

2. **Mechatronic Design and Development of the Actuator**

   Mechanics
   - Introduce compliance
   - Introduce damping

   Electronics
   - Power
   - Control

3. **Control**

   Regulate impedance (how?)
   - Stiffness (?)
   - Damping

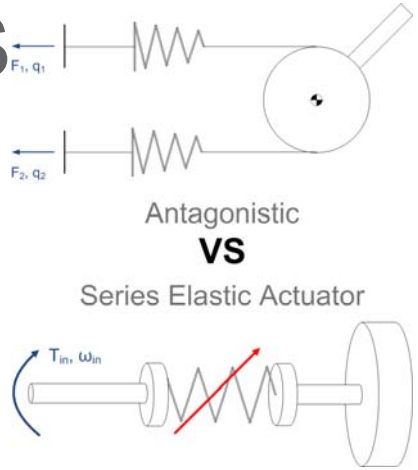
SPECS

COMPLEXITY:

VSA: 2X
VSA+damping : 3X

Development phases

1. **Analysis between antagonistic and series actuation**
   - Energy consumption



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2. **Design and control of the Compliant actuation unit**
   - SEA
   - Fixed passive compliance
   - Variable active compliance

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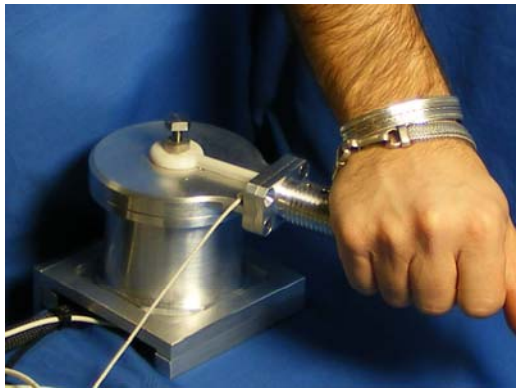
3. **Design and control of the VPDA**
   - introduces variable physical damping
   - to be used in compliant joints



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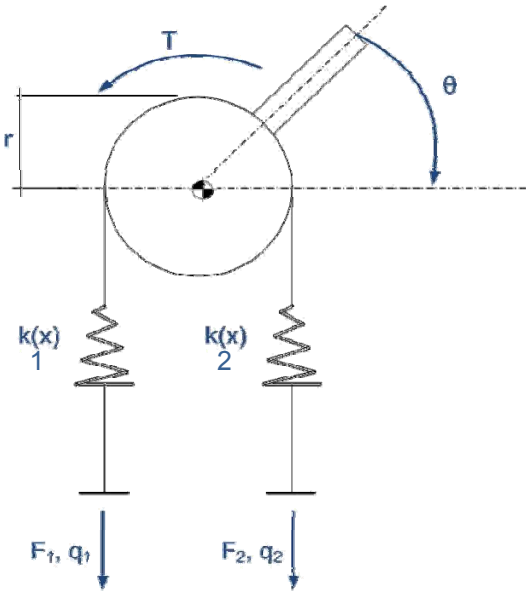
Antagonistic VS SEA - Models

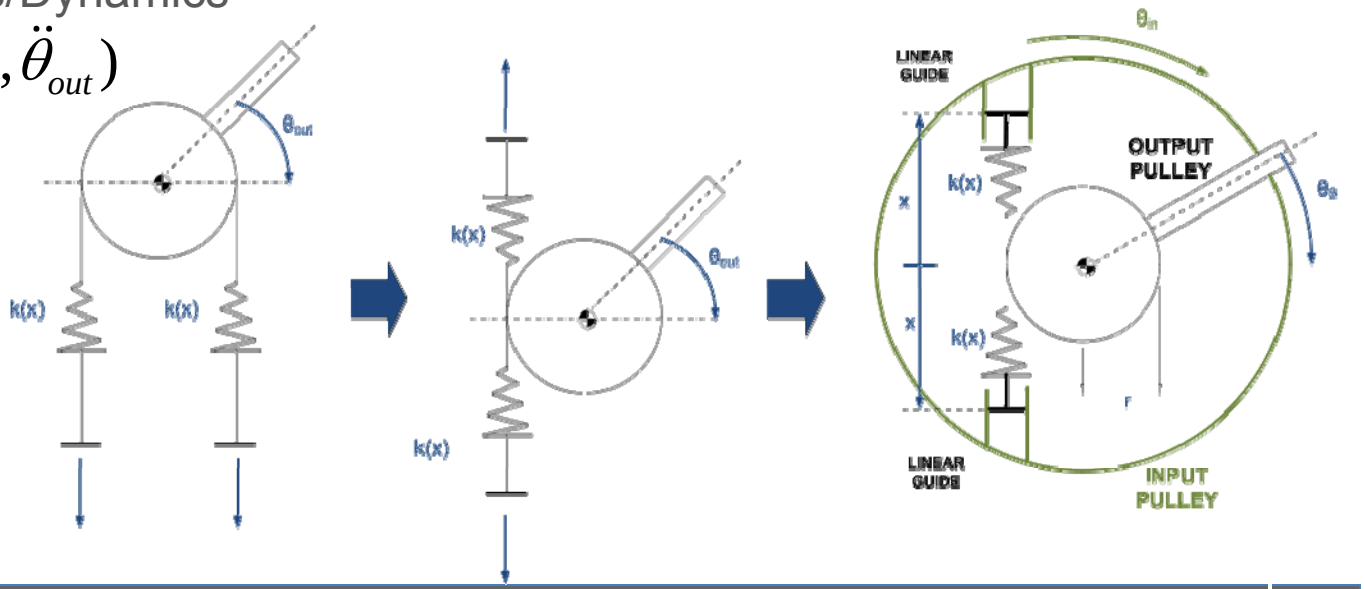
- **ANTAGONISTIC**
  - Inverse Kinematics/Dynamics

$$q_1, q_2(k_{tors}, \theta, \dot{\theta}, \ddot{\theta})$$



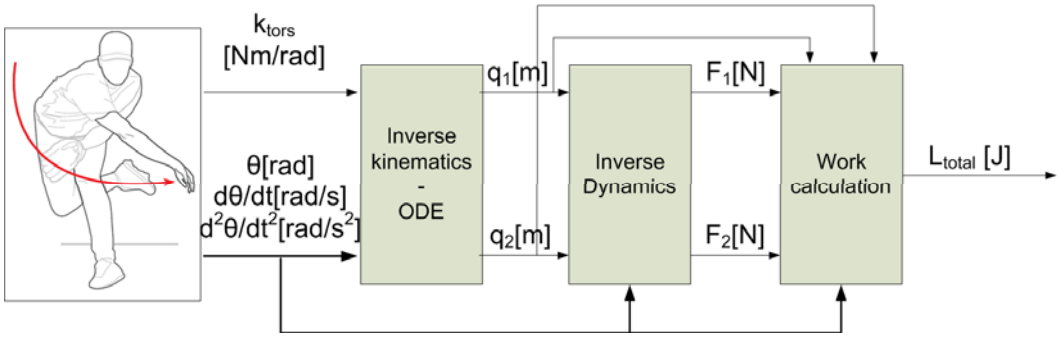
- **SEA**
  - Inspired by antagonistic
  - Inverse Kinematics/Dynamics

$$\theta_{in}, x(k_{tors}, \theta_{out}, \dot{\theta}_{out}, \ddot{\theta}_{out})$$

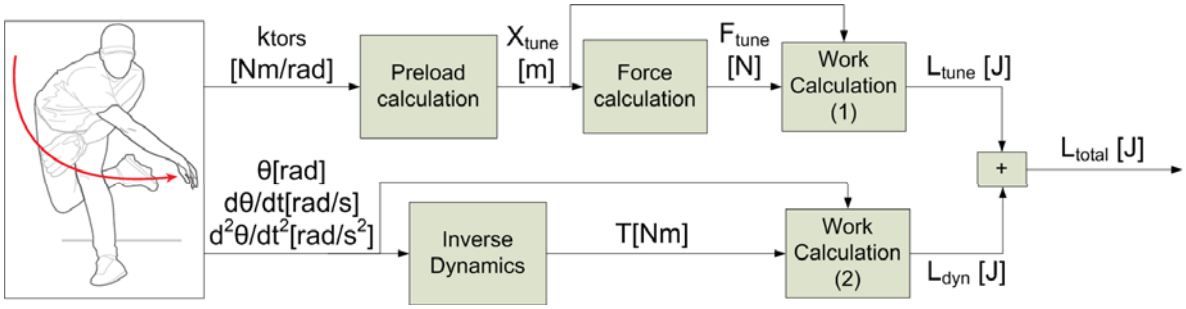


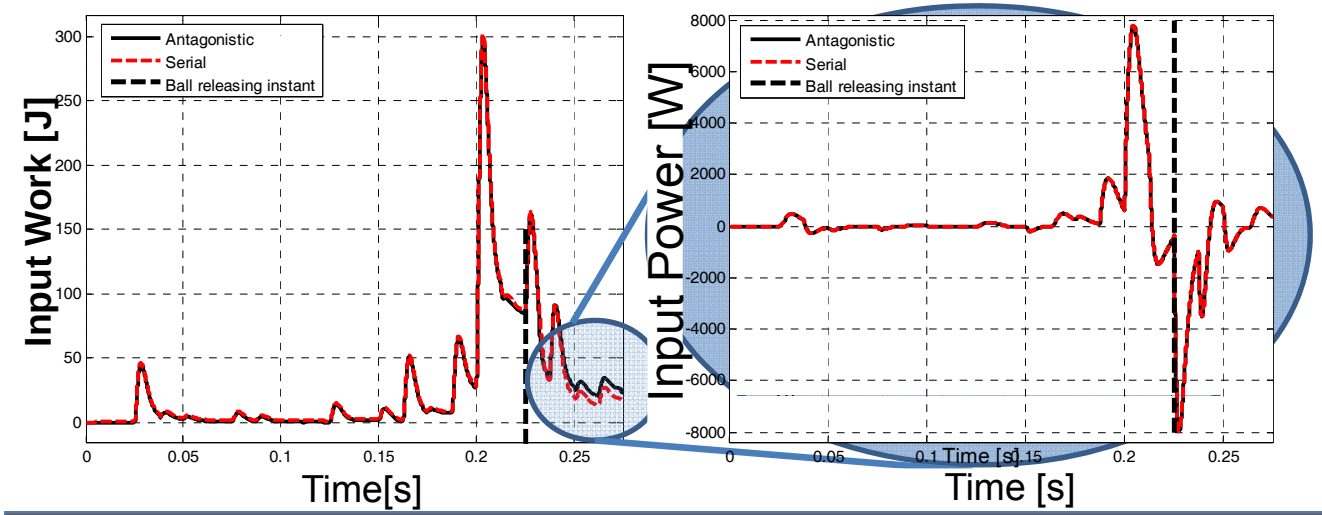
Antagonistic VS SEA - Simulation

ANTAGONISTIC SIMULATOR



SERIAL SIMULATOR





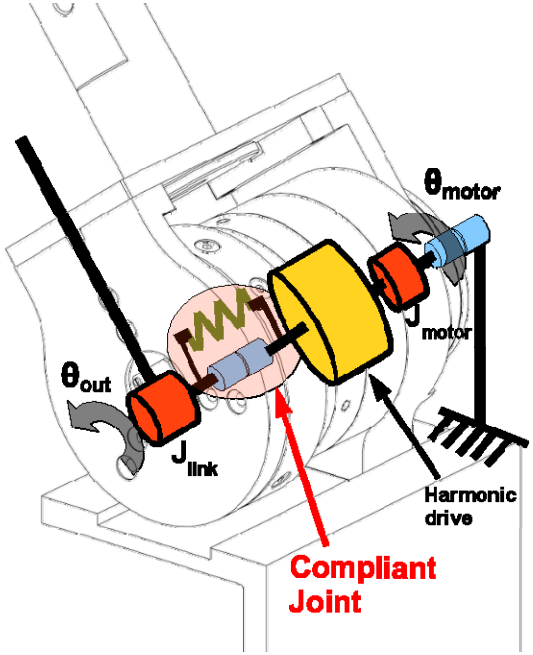
- required work difference
- energy is retained in the springs
- **SEA** is **more efficient**

(in this case!)

Compliant Actuation Unit

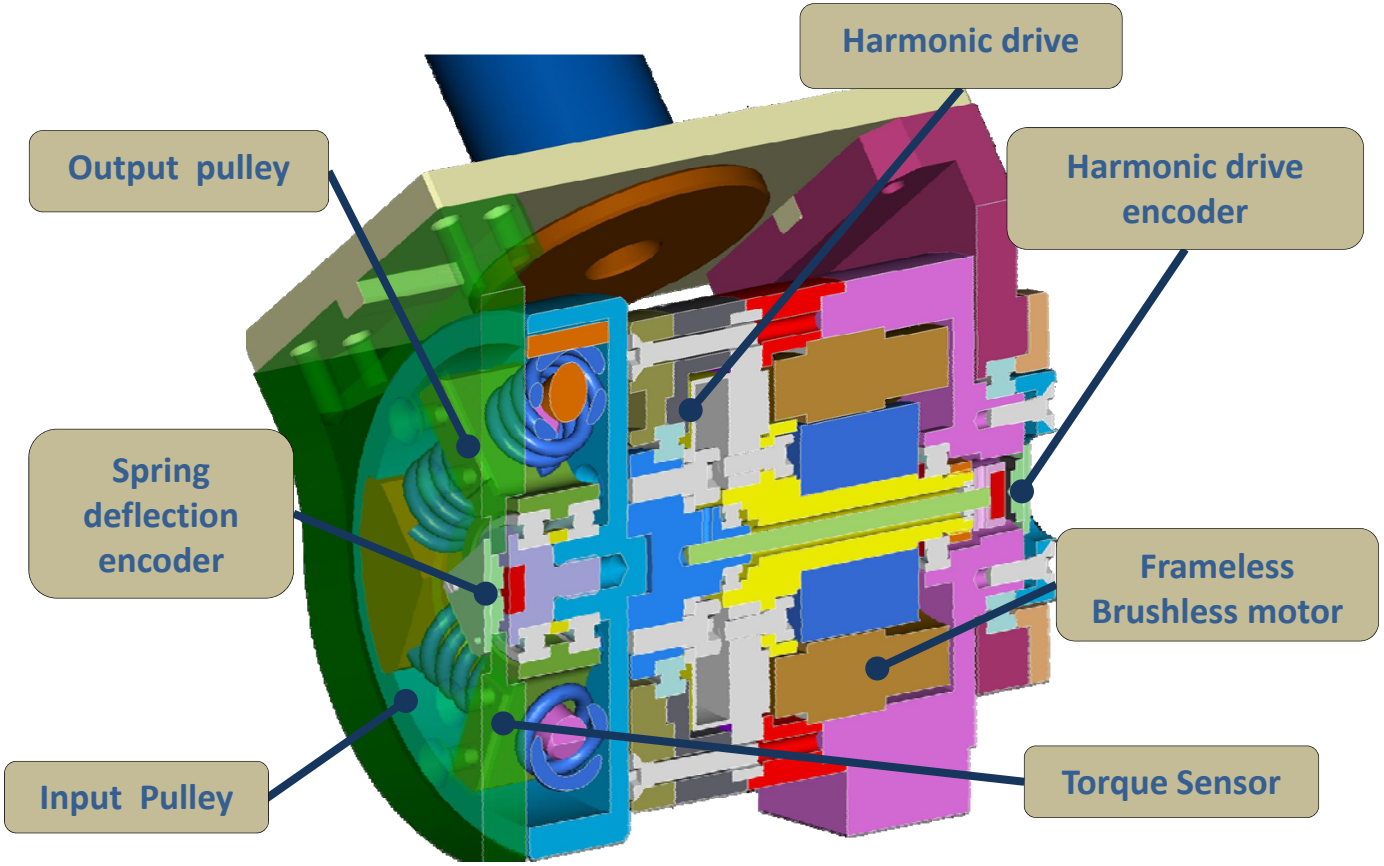
Features

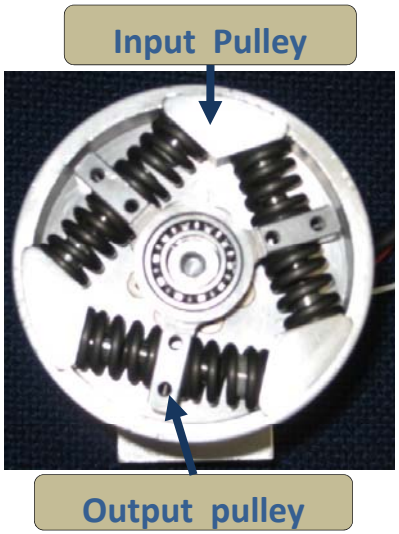
- Modular
- Small size
- Introduces “real” passive compliance
- Adjustable active compliance
- Provide full joint state measurement
  - Gearbox position
  - Outer link position
  - Joint torque



Compliant Actuation Unit

Input pulley: rigidly linked with the gear's outer shaft
Output three spoke part: rigidly linked with the link
} SPRINGS



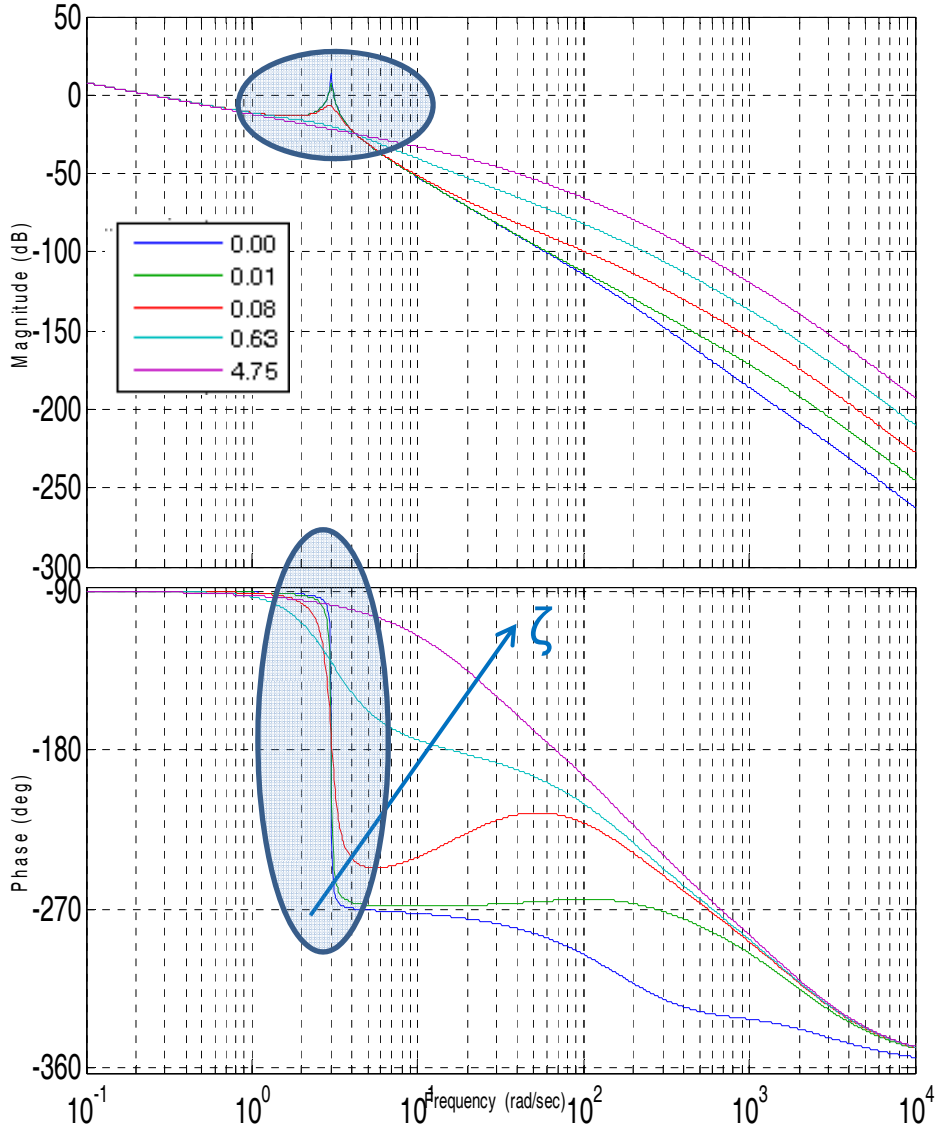


Control Issues – effect of physical damping

Link position/Voltage TF

- Compliance → 2 mechanical poles: 180° phase lag
- 270° phase lag after mechanical poles: difficult to control
- Phase lag is more smooth with physical damping

→ Easier to control



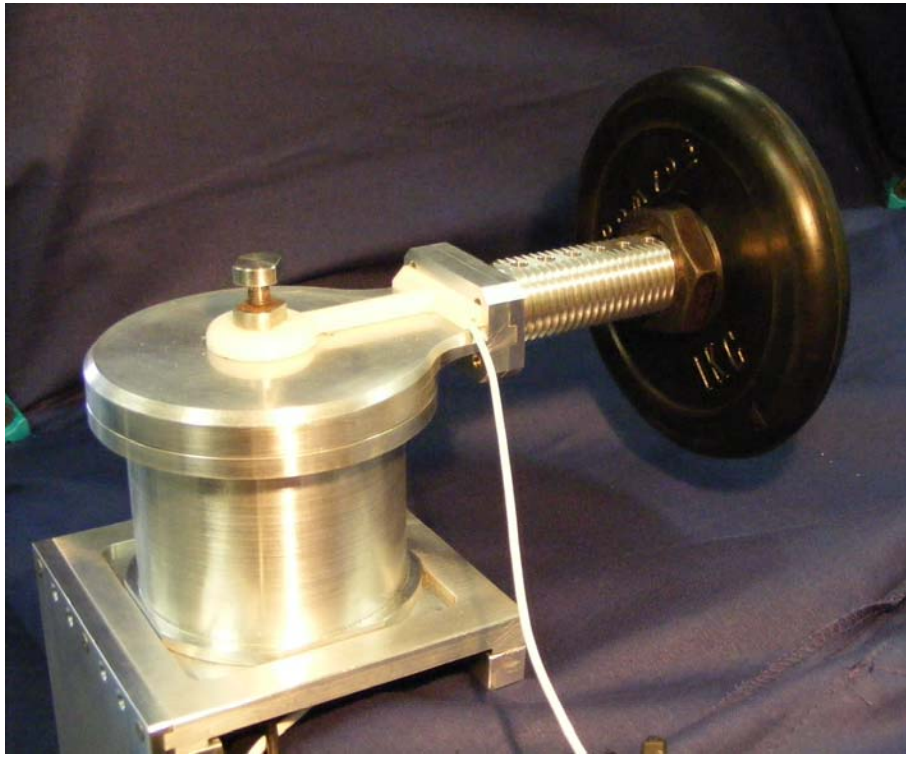
VPDA

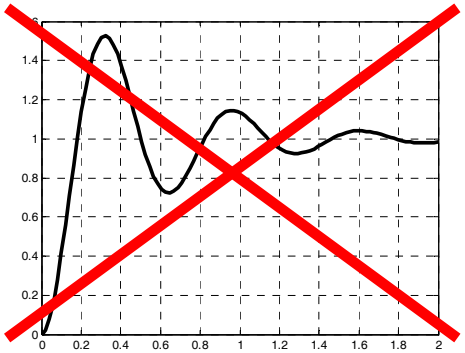
Motivation

- Facilitate control
  - Damp vibrations
  - Inherently passive
  - Damping action is not limited by the mechanical bandwidth of the joint actuator
- Manage energy of the spring

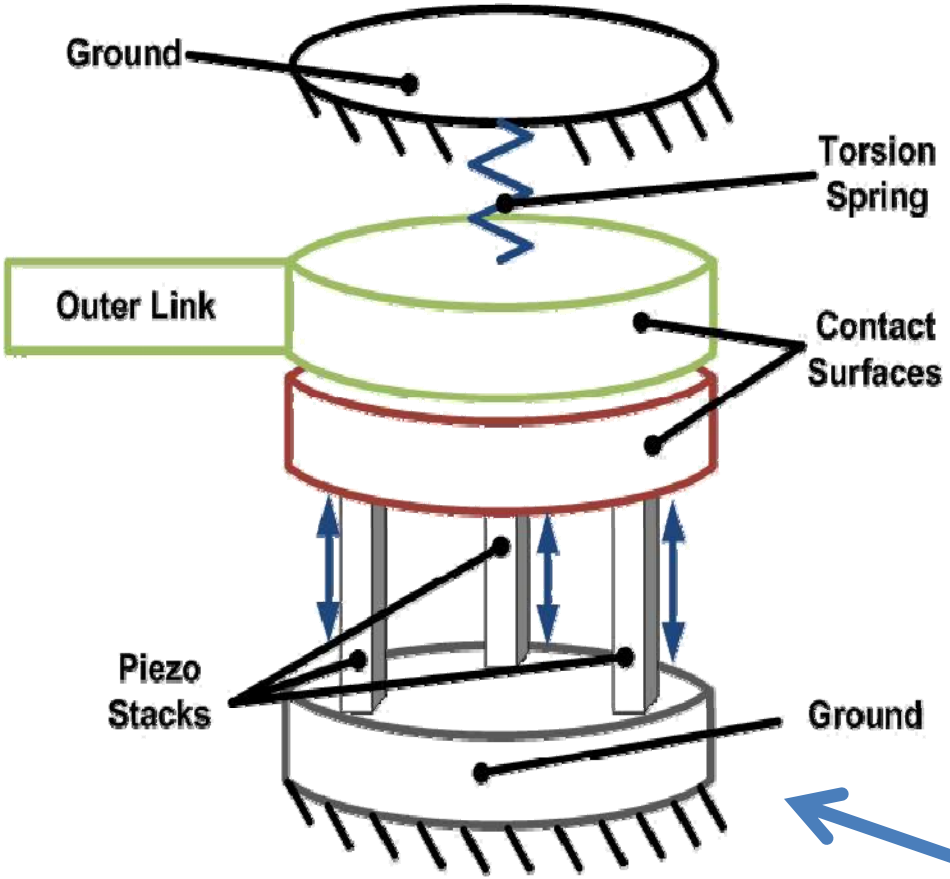
Principle & Features

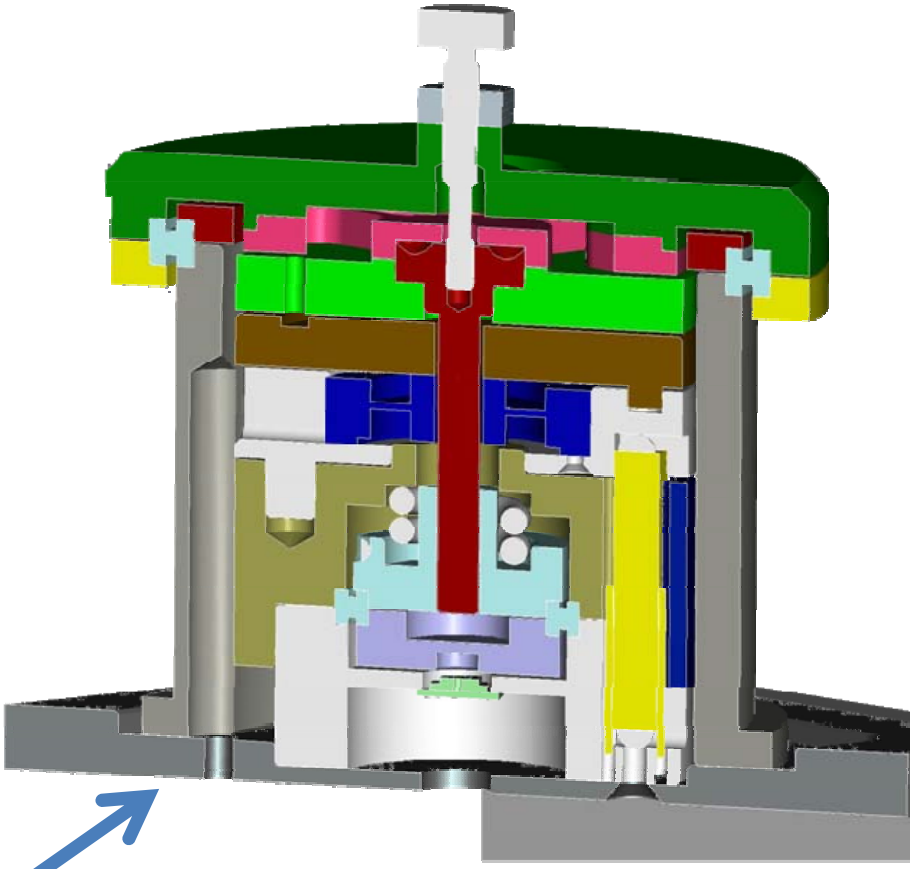
- Semi-Active Solution
- Introduces **"real"** physical damping
- Piezoelectric actuation

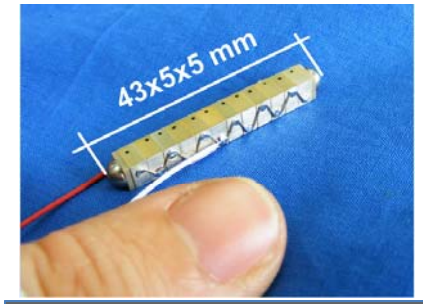


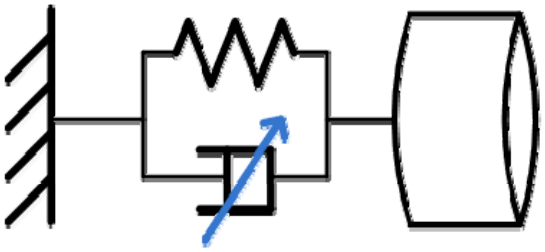


VPDA - Mechanism



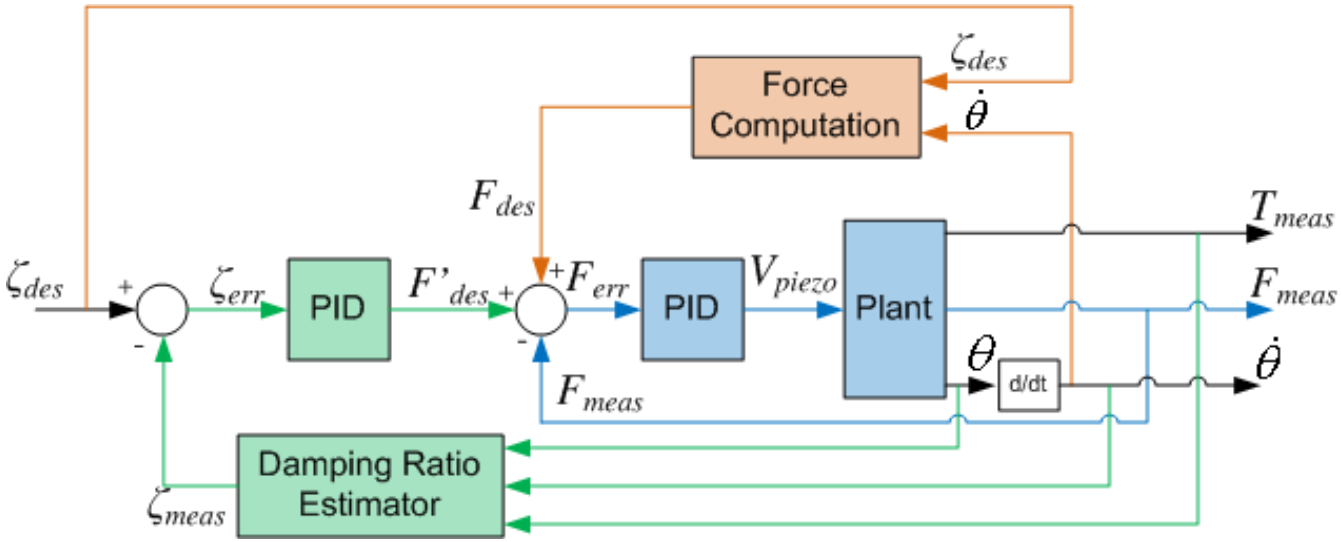


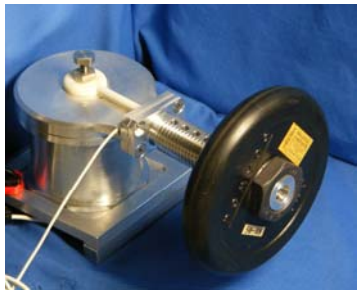




VPDA - Control

- **Inner Force loop**
- **Outer Damping loop**
  - Damping ratio
  - Viscous damping coefficient
- **FFWD Block**
  - Desired damping level
  - Link velocity





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Conclusions

1. Preliminary analysis phase

   - **Actuator's design should depend on:**
     - **task**
     - **objective criteria (energy exp., performances, safety..)**
     - **…**

   } **AFFECT FINAL PERFORMANCE**

2. Design

   - **Introduction of**
     - **Compliance**
     - **(Damping)**

   } **DEPENDS ON MECHANICAL CONSTRAINS**

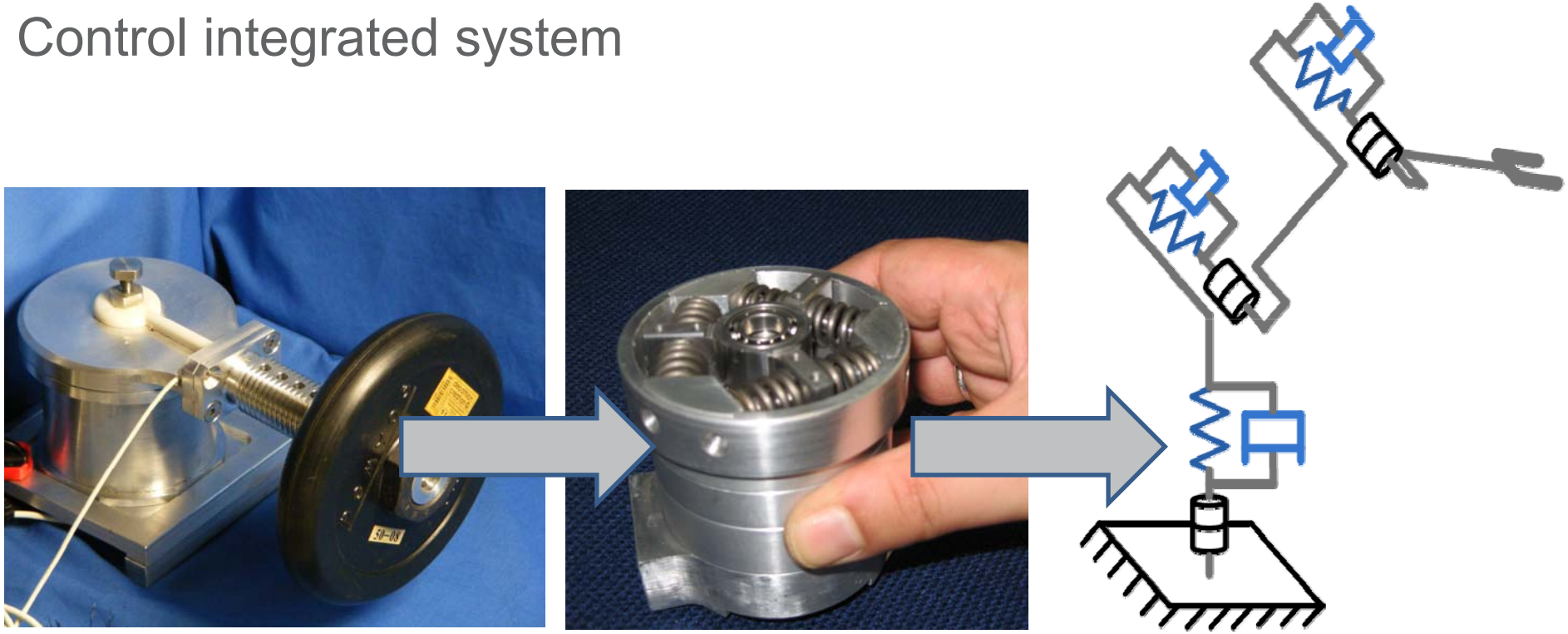
3. Control

   - Regulate stiffness (active or passive)
   - Regulate damping (active or passive)
   - **Satisfy Objective criteria**

   } **EXPLOIT THE VARIABLILITY OF IMPEDANCE**

Future work

- Implement VPDA in the Compliant Actuation Unit
- Design a Multi DOF damped compliant system
- Control integrated system



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http://www.viactors.eu/

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Thank you for your attention

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