ACADEMIA BRASILEIRA DE CIÊNCIAS

MCMXVI

#imaginando o futuro

REUNIÃO MAGNA . 2018

40 ANOS

Materiais e Estruturas Inteligentes: estado da arte e perspectivas

(Smart Structures and Materials: state-of-the-art and perspectives)

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(vsteffen@ufu.br)

LMEst

FEMEC

inct institutos nacionais de ciência e tecnologia

UNIVERSIDADE FEDERAL DE UBERLÂNDIA
FACULDADE DE ENGENHARIA MECÂNICA
Instituto Nacional de Ciência e Tecnologia de Estruturas Inteligentes em Engenharia

SMART MATERIALS AND STRUCTURES

SMART MATERIALS OR ADAPTATIVE: showing coupling between various physical areas (converting different forms of energy), their characteristics can be modified by controlled alterations of the state variables which determines the physical areas.

SMART STRUCTURES: use smart materials' properties to give the desired functionnality :

- vibration control

- position control

- shape control

- structural health monitoring

- generation of energy

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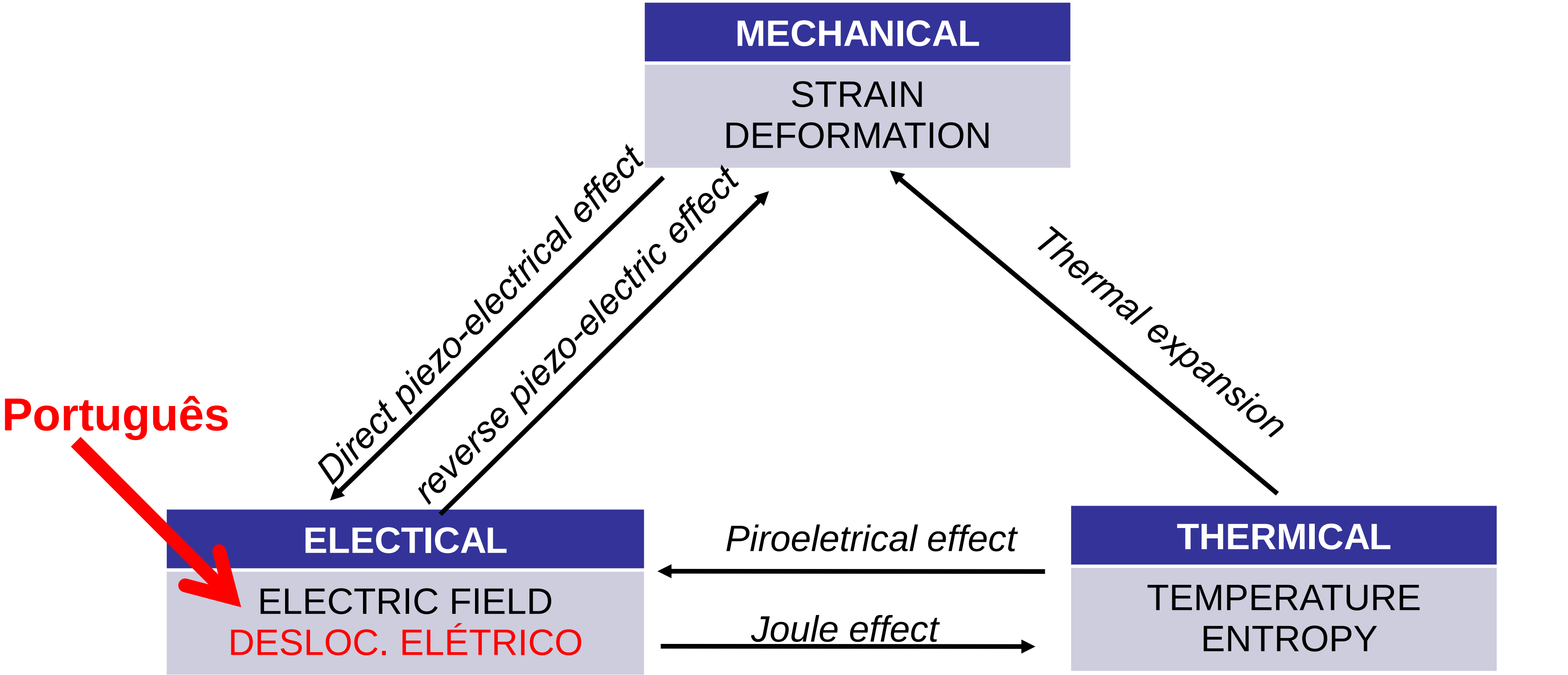
SMART MATERIALS AND STRUCTURES

DOMAIN	State variable	DOMAIN	State variable
MECHANICAL	STRAIN DEFORMATION	MAGNETIC	MAGNETIC FIELD MAGNETIC FLUX
ELECTRICAL	CAMPO ELÉTRICO DESLOCAMENTO ELÉTRICO	CHEMICAL	CONCENTRATION VOLUMETRIC FLUX



SMART MATERIALS AND STRUCTURES

PIEZOELECTRIC MATERIALS	ELETROACTIVE POLIMERS
MECHANICAL ELECTRICAL	MECHANICAL ELECTRICAL

MATERIALS WITH SHAPE MEMORY	ELETRO-REOLOGIC FLUIDS
MECHANICAL THERMAL	MECHANICAL ELECTRICAL

MAGNETO-REOLOGIC FLUIDS
MECHANICAL MAGNETICAL

MATERIALS WITH SHAPE MEMORY

They are metal alloys that can produce large mechanical deformations when heated or cooled.

Exemples:

- **Nitinol (NOL-Naval Ordnance Laboratory): recoverable deformation of 6%**

CuZnAl: recoverable deformation of 2%

The ability of SMA to recover large deformations result from phase transformations that occur due to the application of mechanical stress and heat.

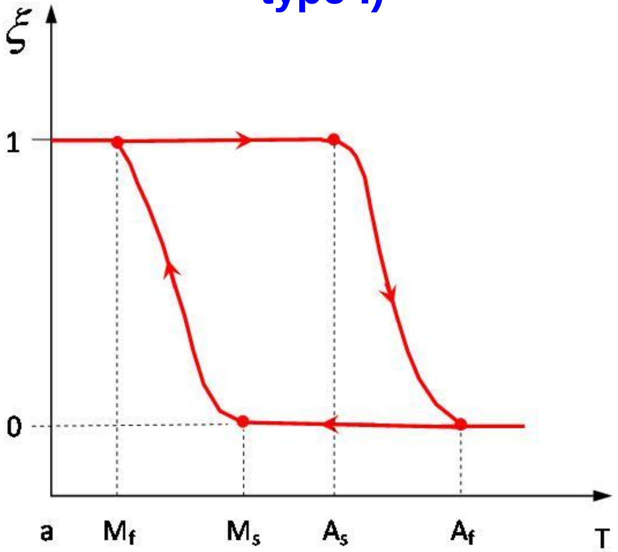
The relevant phase transformations are the transformations of austenite at high temperatures, in a free state of tension, to different variants of martensite at low temperatures.

MATERIALS WITH SHAPE MEMORY

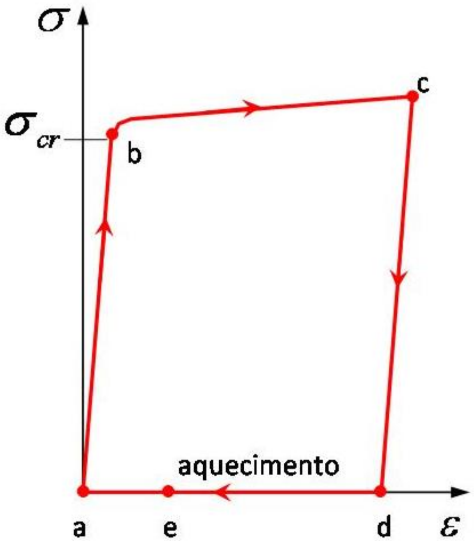
The phase transformations between austenite and martensite induce large mechanical deformations, producing the effects of shape memory and pseudo-elasticity.

Operational characteristics as actuators: Large displacements, large forces and low frequencies.

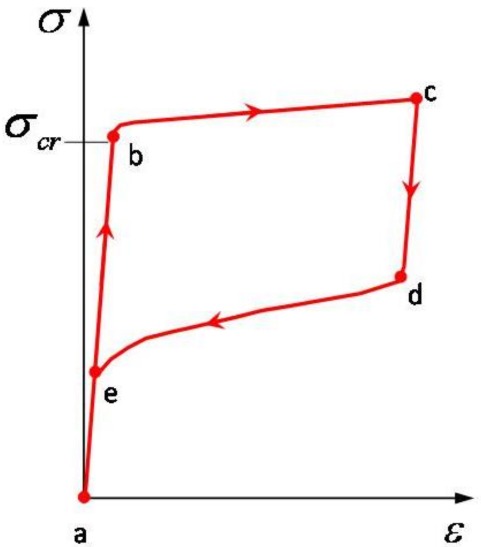
Phase changes due to temperature variation (Material type I)



Shape memory effect

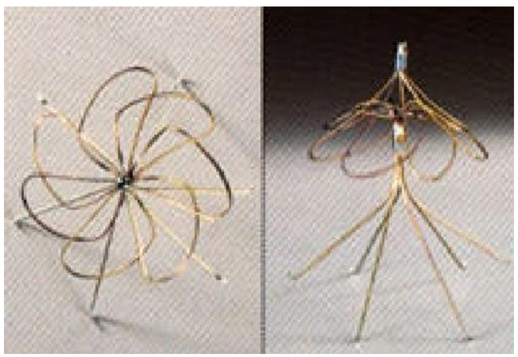


Pseudo-elasticity



MATERIALS WITH SHAPE MEMORY

Exemples of applications:



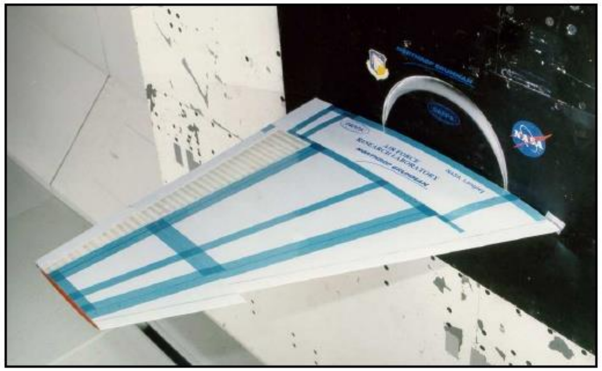
Simon filter for filtering blood clots in the bloodstream

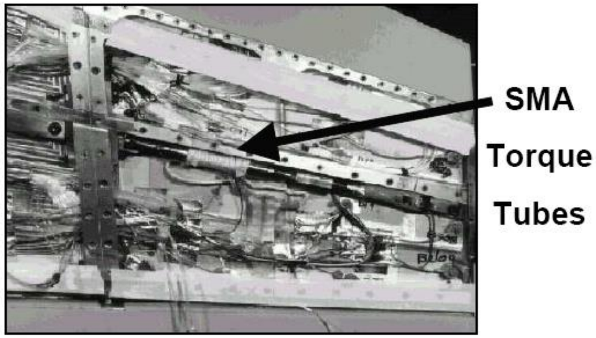
Expanders (stents) used to support the internal diameter of blood vessels, esophagus and bile duct.

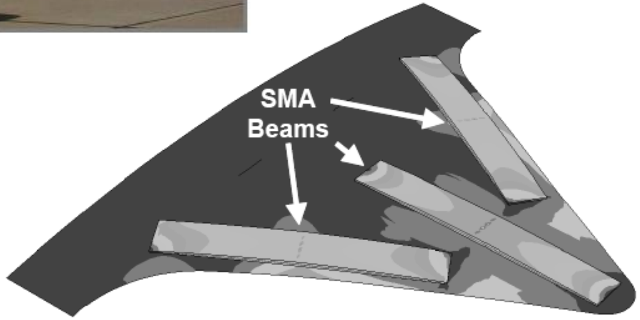
Robotic muscles

MATERIALS WITH SHAPE MEMORY

D. Lagoudas, D. Hartl, Aerospace Applications of Shape Memory Alloys, Proceedings of the Institution of Mechanical Engineers, Part G, Journal of Aerospace Engineering, Vol. 221 (Special Issue), 2007, pp. 535–552.

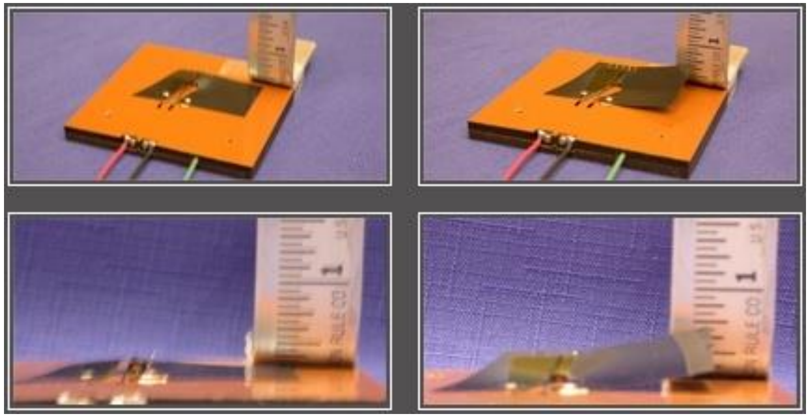






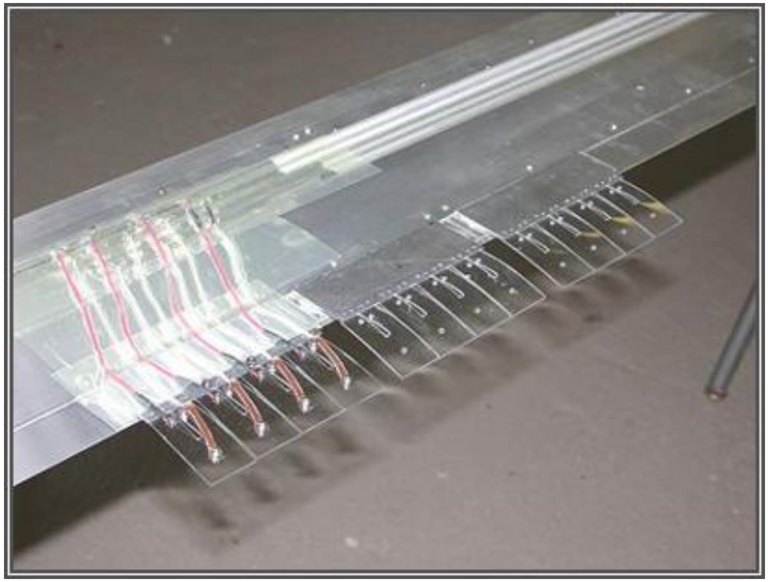
MATERIALS WITH SHAPE MEMORY

Vortex generators in fixed wing



• **Improvement of aerodynamic characteristics**

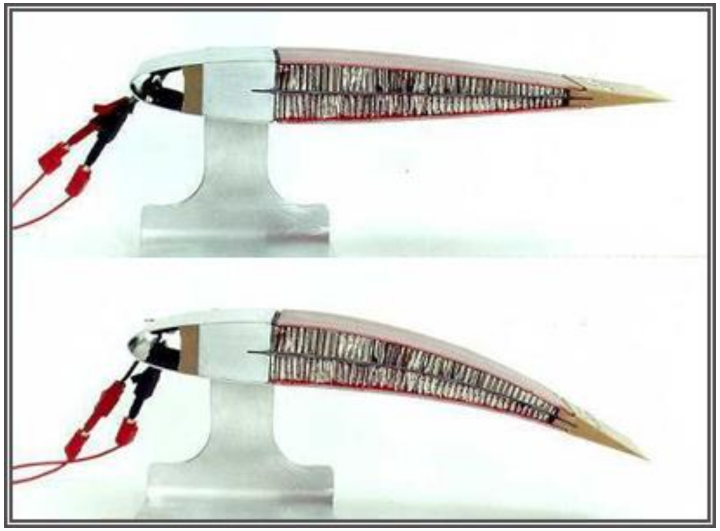
Actuators for helicopter propeller blades

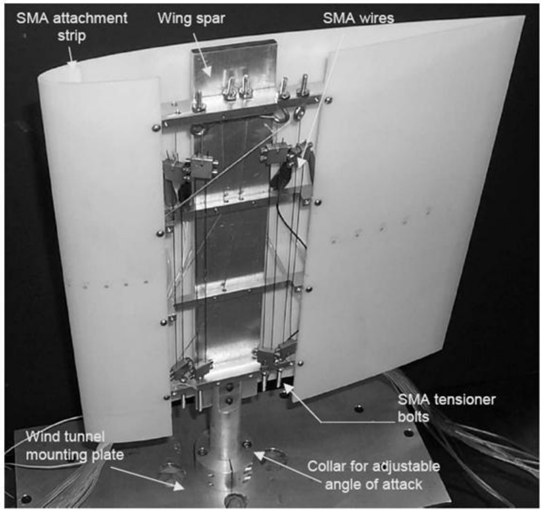


- **Reduction of vibration / noise**
- **Improvement of aerodynamic characteristics**
- **Temporary reinforcement**

(Continuum Dynamics, Inc., http://www.continuum-dynamics.com)

Variable geometry airfoils





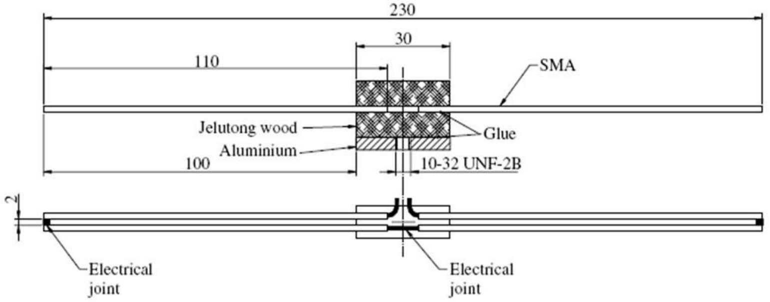
Improvement of aerodynamic characteristics
Simplification of the drive system of control surfaces

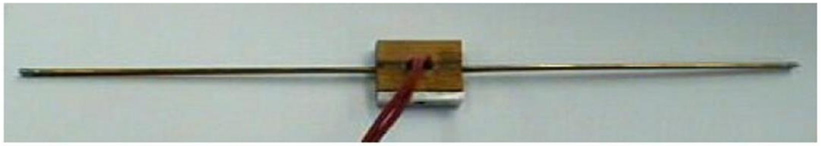
Strelec, J.K., Lagoudas, D.C., Khan, M.A., and Yen, J., 2003, "Design and Implementation of a Shape Memory Alloy Actuated Reconfigurable Wing," Journal of Intelligent Material Systems and Structures, Vol. 14, pp. 257-273.

(Continuum Dynamics, Inc., http://www.continuum-dynamics.com)

MATERIALS WITH SHAPE MEMORY

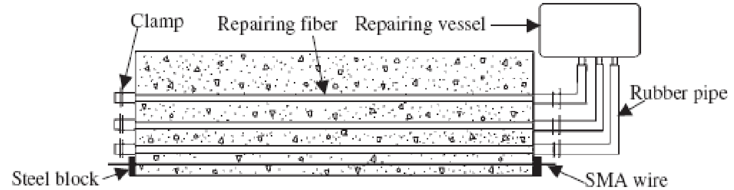
Adaptive dynamic vibration absorber

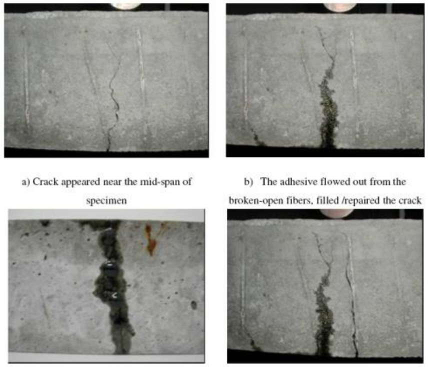




Rustighi, E., Brennan, M.J. and Mace, B.R. A shape memory alloy adaptive tuned vibration absorber: Design and implementation, *Smart Materials and Structures*, 14, 2005, 19-28

Self-healing beam





a) Crack appeared near the mid-span of specimen

b) The adhesive flowed out from the broken-open fibers, filled /repaired the crack

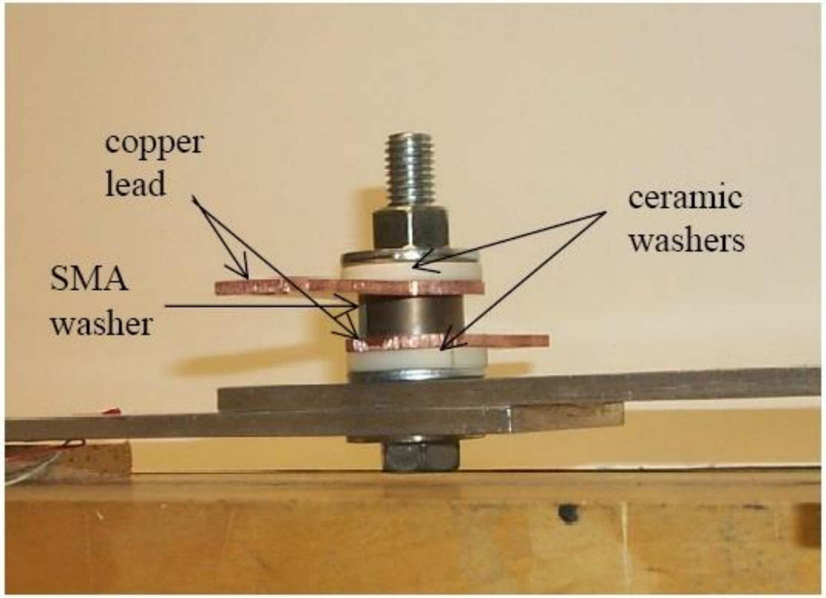
c) Crack repaired in the bottom of Specimen

d) Original crack from the first loading did not reopen but new cracks formed

Yachuan Kuang, Jinping Ou, Self-repairing performance of concrete beams strengthened using superelastic SMA wires in combination with adhesives released from hollow fibers. Smart Mater. Struct. 17, 2008.

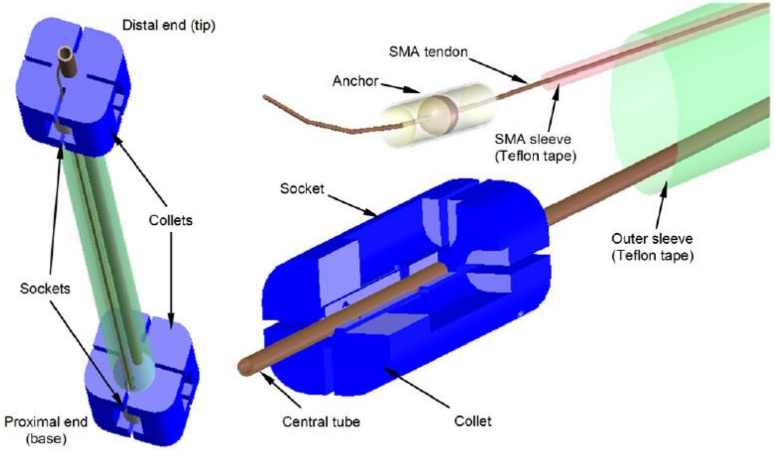
MATERIALS WITH SHAPE MEMORY

Self-healing screw joint



Pairs, D., Development of a Self-Sensing and Self-Healing Bolted Joint, Master thesis, Virginia Polytechnique Institute and State University, 2006.

Cateter with shape memory

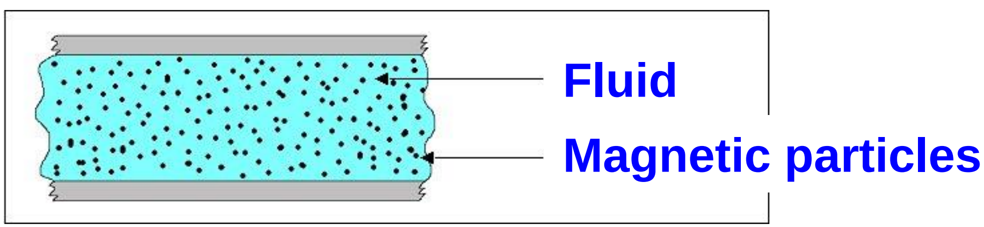


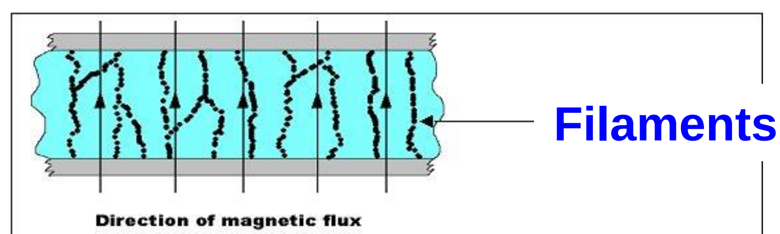
Arun S Veeramani, Gregory D Buckner, *Stephen B. Owen,* Richard C. Cook, Gil Bolotin. Modeling the dynamic behavior of a shape memory alloy actuated catheter. Smart Mater. Struct. 17 (2008)

MAGNETO-REOLOGIC FLUIDS

They are dispersions of solid metal particles in a fluid that present significant reversible changes in rheological characteristics (viscosity apparent) when subjected to an external magnetic field.

MR fluids typically consist of a volume fraction of 20% to 40% of iron particles from 3 to 10μm of diameter, in mineral oil, synthetic oil or glycol, and additives (surfactants).

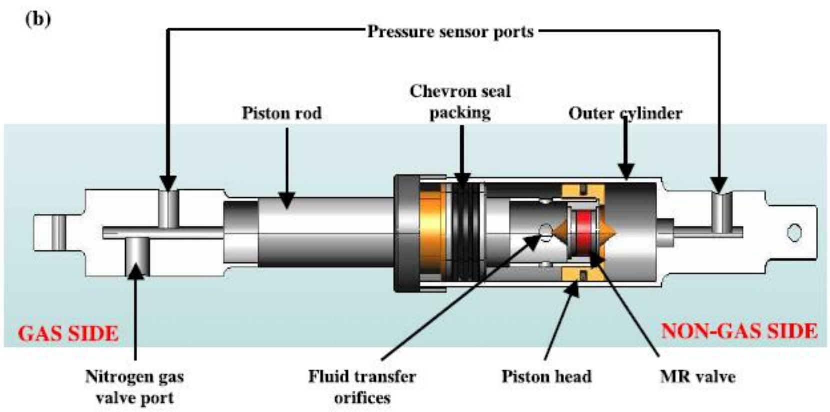


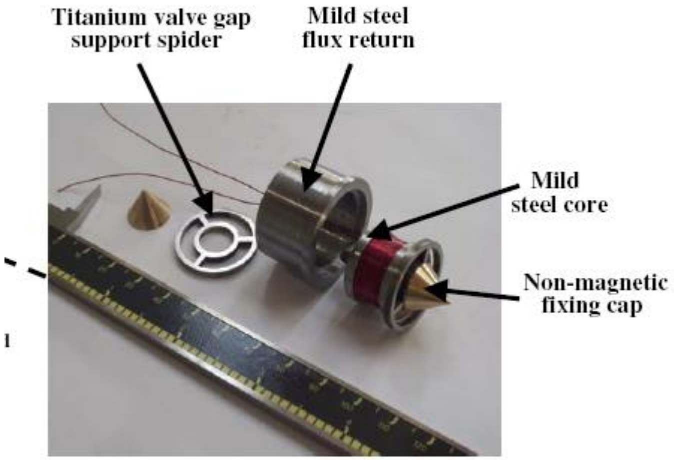


MAGNETO-REOLOGIC FLUIDS

Adaptive suspensions

(http://www.lord.com)



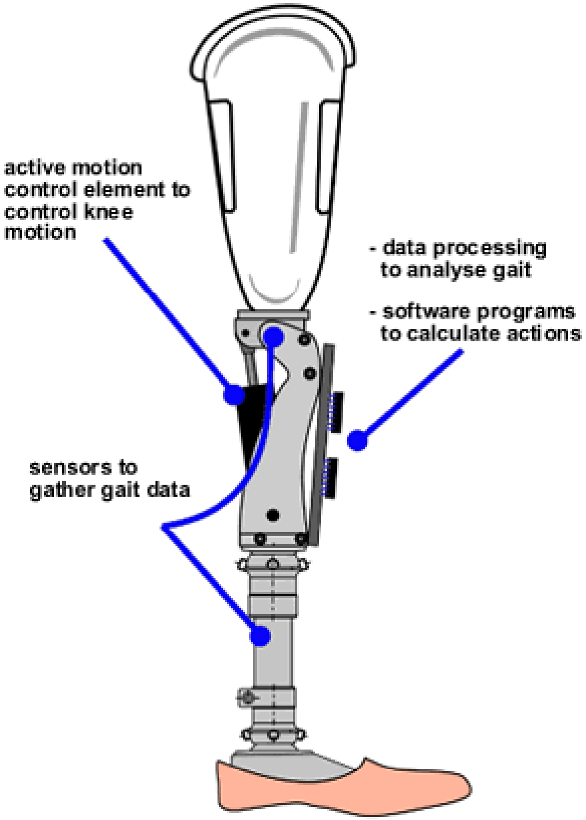


C. Batterbee, N. D. Sims, R. Stanway, M. Rennison, Magnetorheological landing gear: 2. Validation using experimental data. Smart Mater. Struct. 16 (2007) 2441–2452D.

MAGNETICO-REOLOGIC FLUIDS

Adaptative suspensions

Prostheses



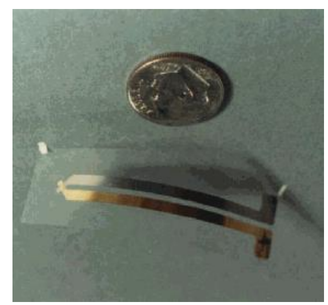
(http://www.lord.com)

PIEZOELETRIC MATERALS

Piezoelectricity is a property of certain materials to produce a distribution of electric charge when subjected to a mechanical stress (direct effect) and change geometry when subjected to an external electric field.

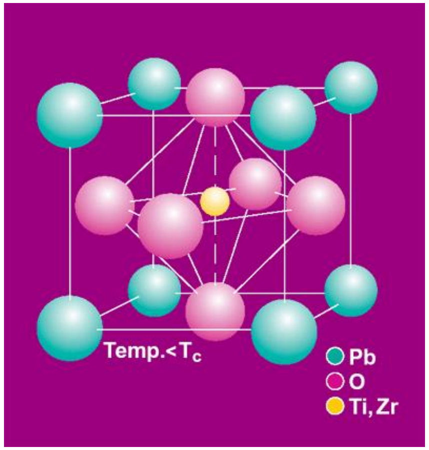
Effect discovered by Pierre and Jacques Curie in 1880.

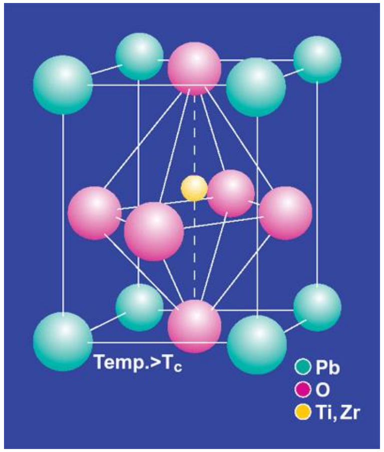
Exemples of Piezoelectric Materials

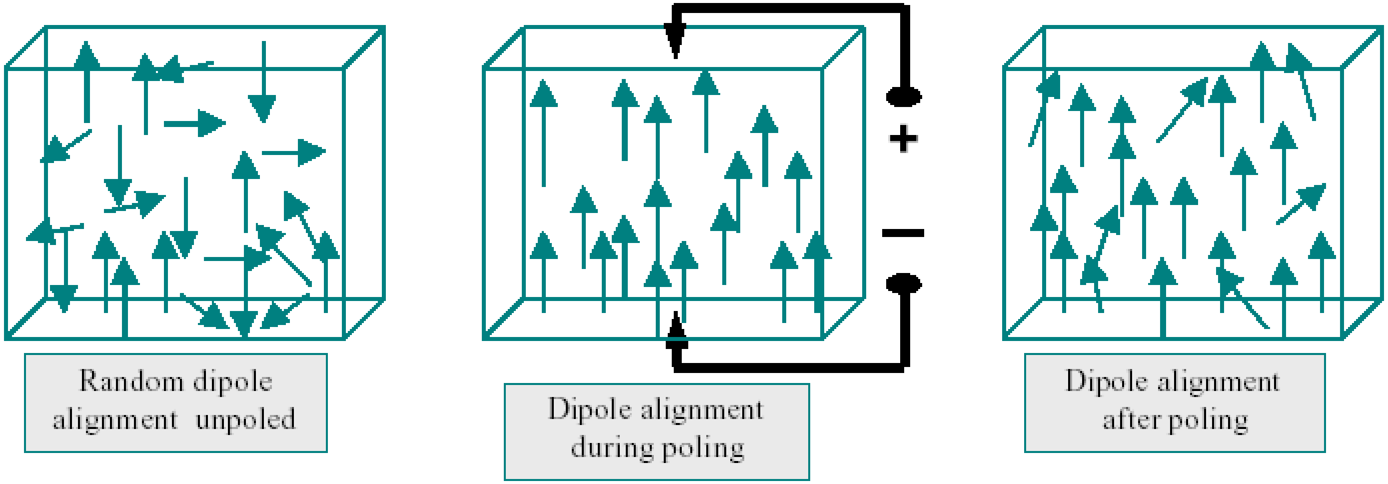


- **Ceramics**
  - Lead Zirconate Titanate (PZT)
  - Barium titanate ($BaTiO_3$)
- **Polimers**
  - PVDF
- **Natural quartz (SiO_2)**
- **Tourmaline**
- **Human bones**

PIEZOELETRIC MATERALS

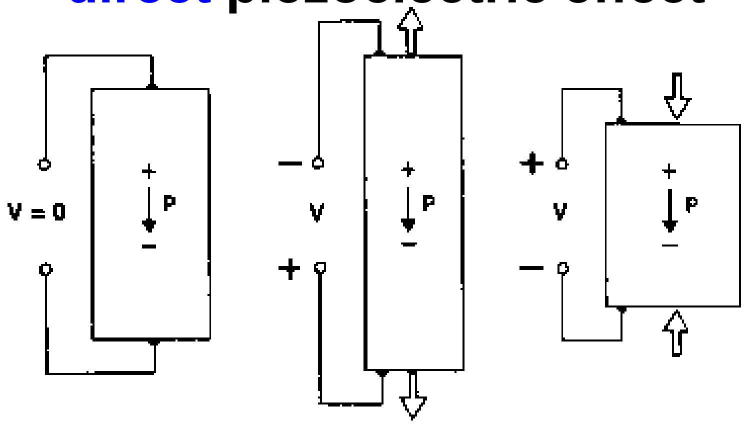




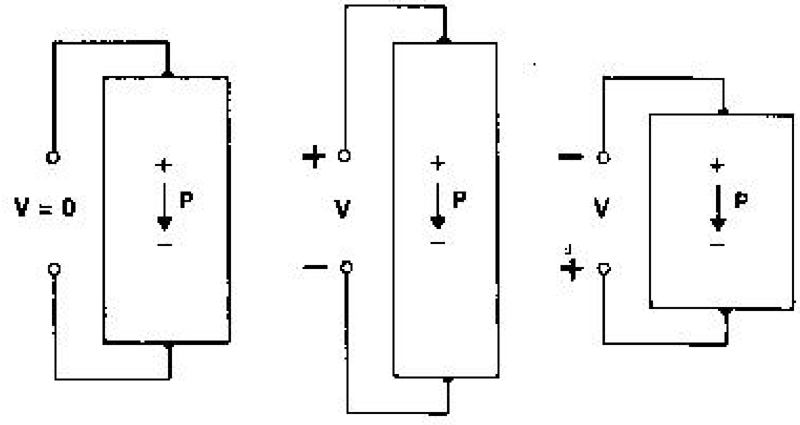


PIEZOELETRIC MATERALS

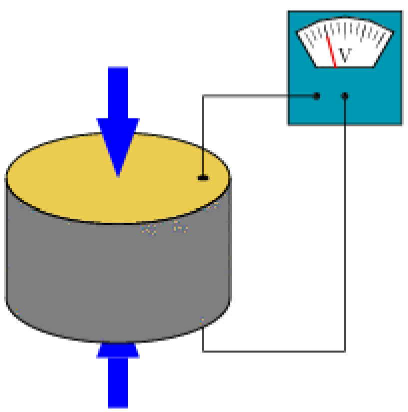
direct piezoelectric effect



indirect piezoelectric effect



Sensors



Actuators

Applications

Sensors (direct effect)

- acceleration
- pressure
- deformation
- strength

Actuators (inverse effect)

- strength
- displacement

Ultrasonic Transducers (operates within 10kHz - 70kHz)

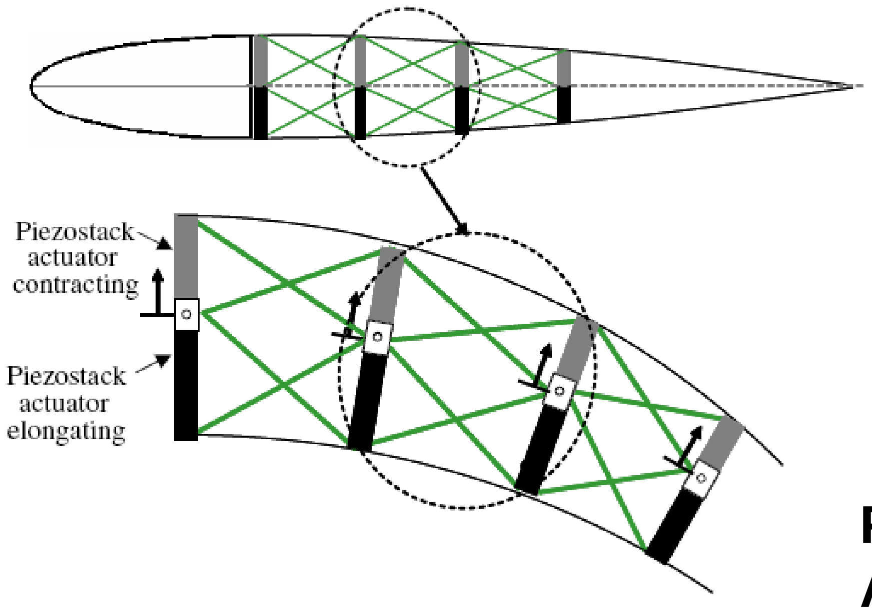
- medical imaging
- non-destructive inspection

Motors (direct effect, operates within 10kHz - 70kHz)

- robotics

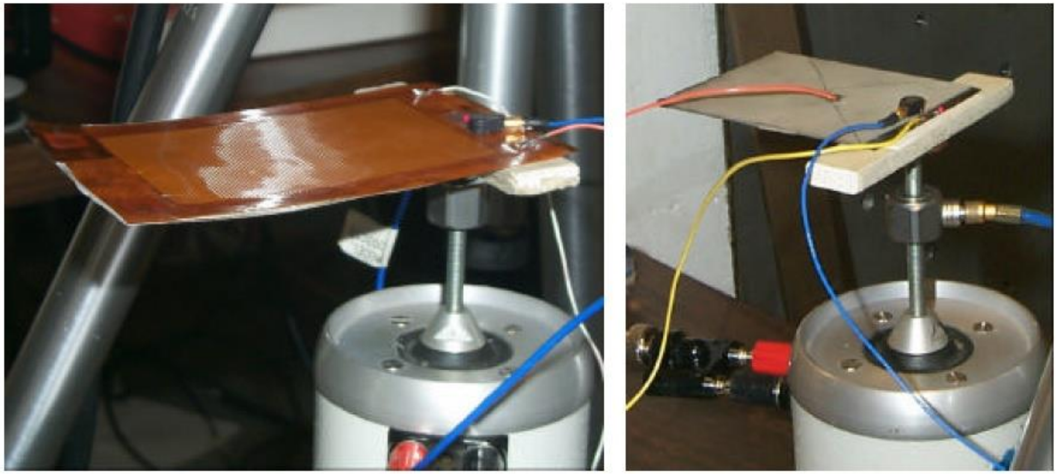
PIEZOELETRIC MATERALS

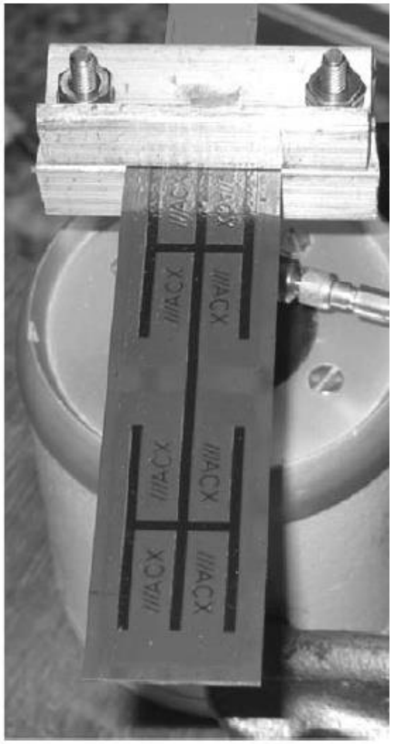
Shape control of aerodynamic profile



Farhan Gandhi,Phuriwat Anusonti-Inthra, Skin design studies for variable camber morphing airfoils. Smart Mater. Struct. 17 (2008)

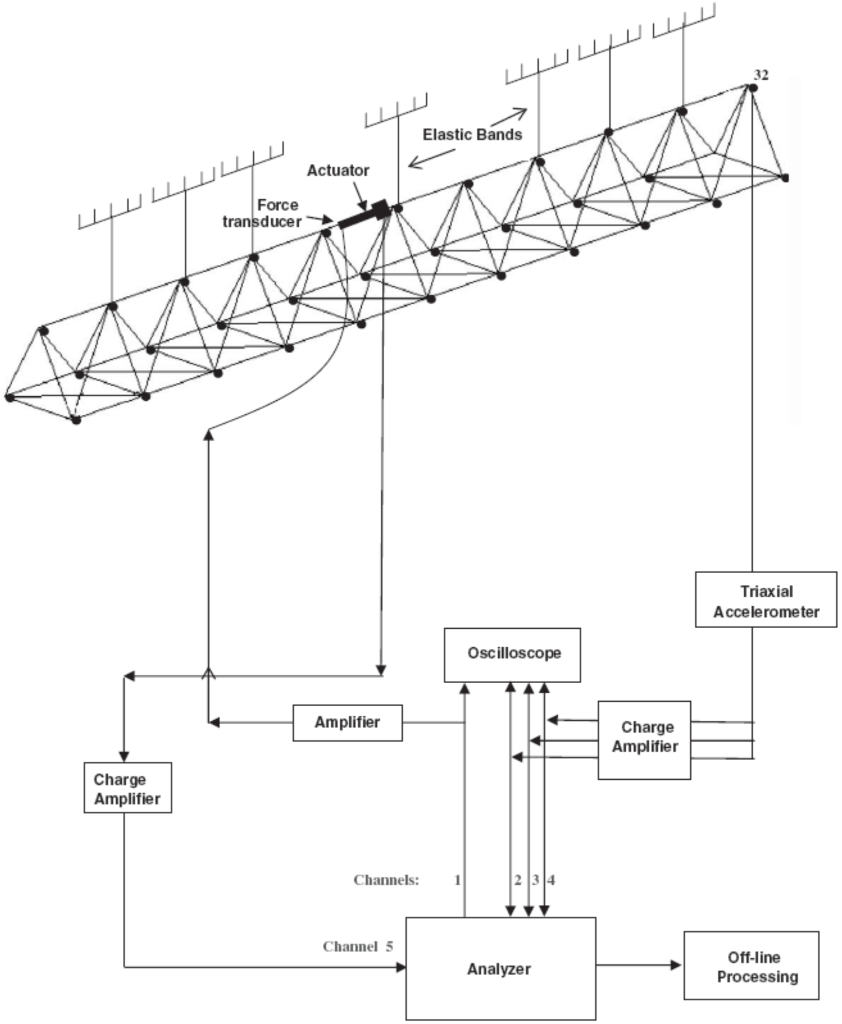
Energy Harvesting





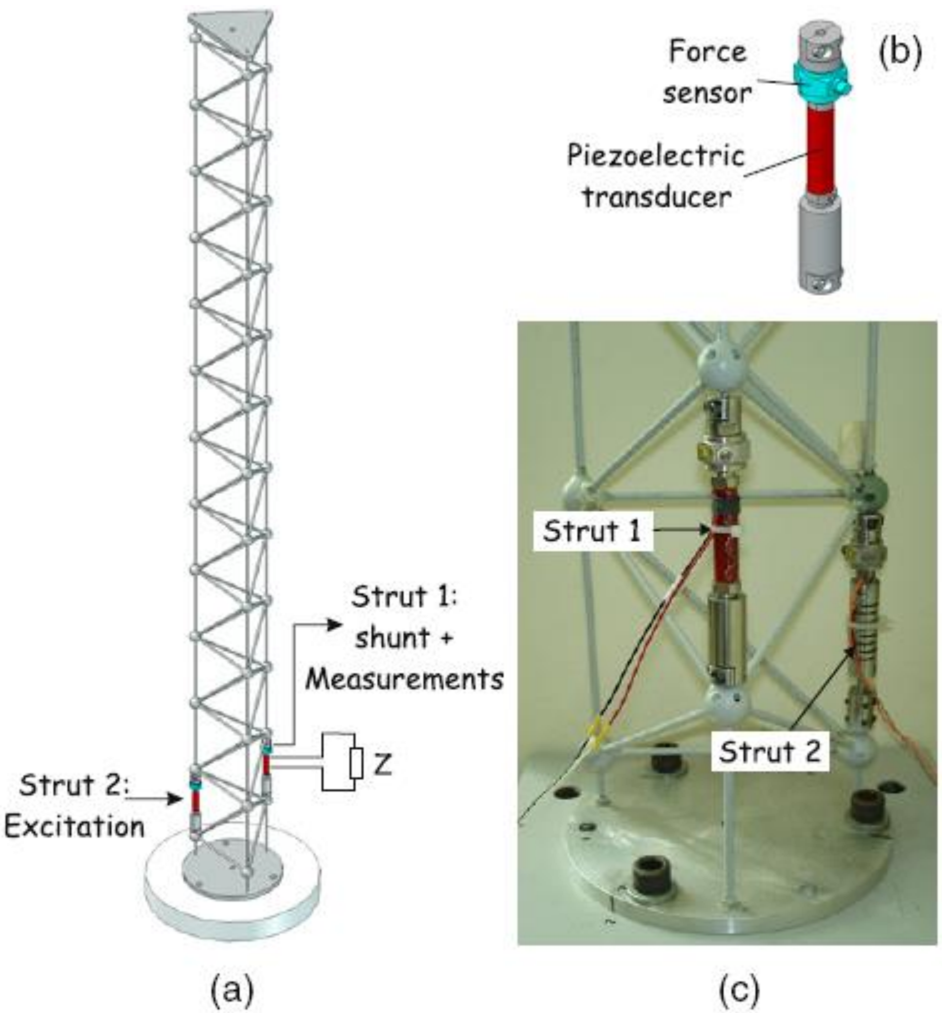
HENRY A. SODANO, DANIEL J. INMAN, GYUHAE PARKComparison of Piezoelectric Energy Harvesting Device for Recharging Batteries. JOURNAL OF INTELLIGENT MATERIAL SYSTEMS AND STRUCTURES, Vol. 16—2005

Active vibration control

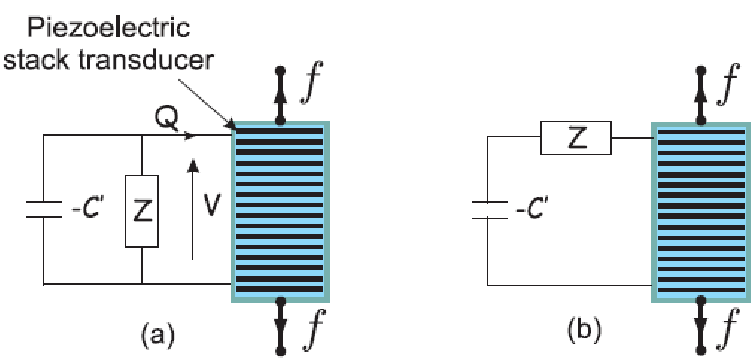


M. Moshrefi-Torbatia,, A.J. Keaneb, S.J. Elliottc, M.J. Brennan, D.K. Anthonyc, E. Rogersd, Active vibration control (AVC) of a satellite boom structure using optimally positioned stacked piezoelectric actuators
Journal of Sound and Vibration 292 (2006) 203–220

Passive vibration control

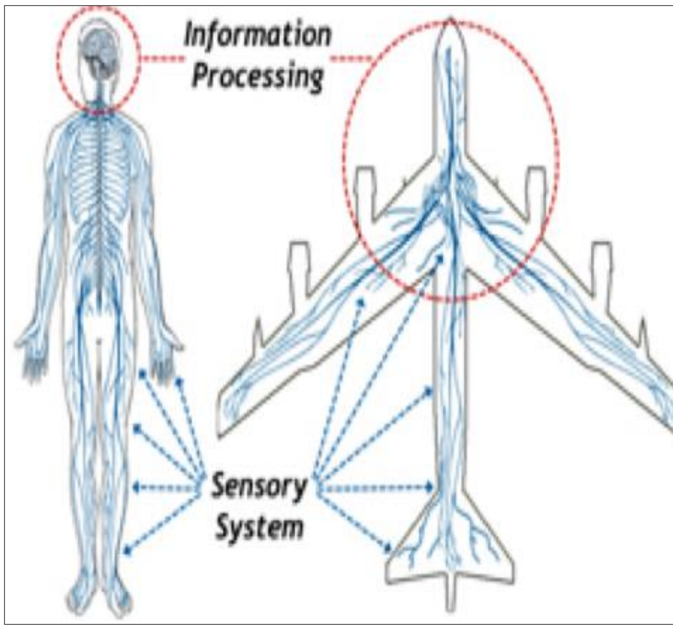


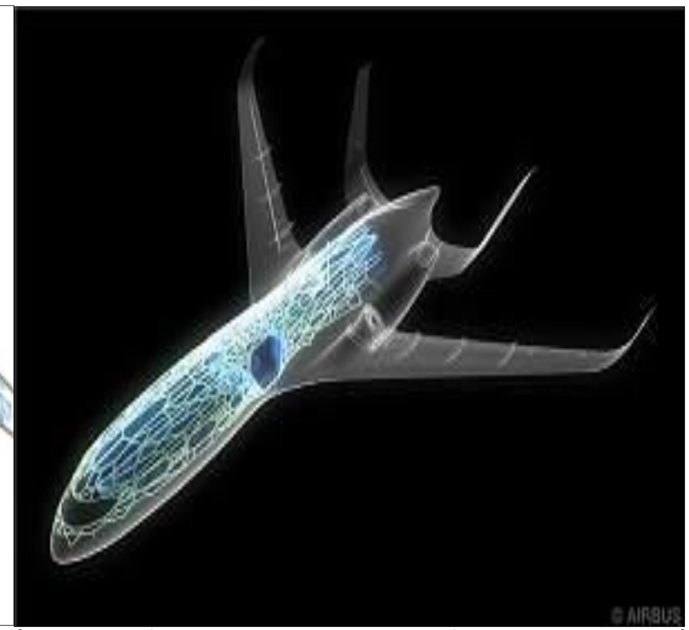
Marneffe, B., Preumont, A. Vibration damping with negativecapacitance shunts: theory and experiment. Smart Mater. Struct. 17 (2008)



PIEZOELETRIC MATERALS

Structural Health Monitoring

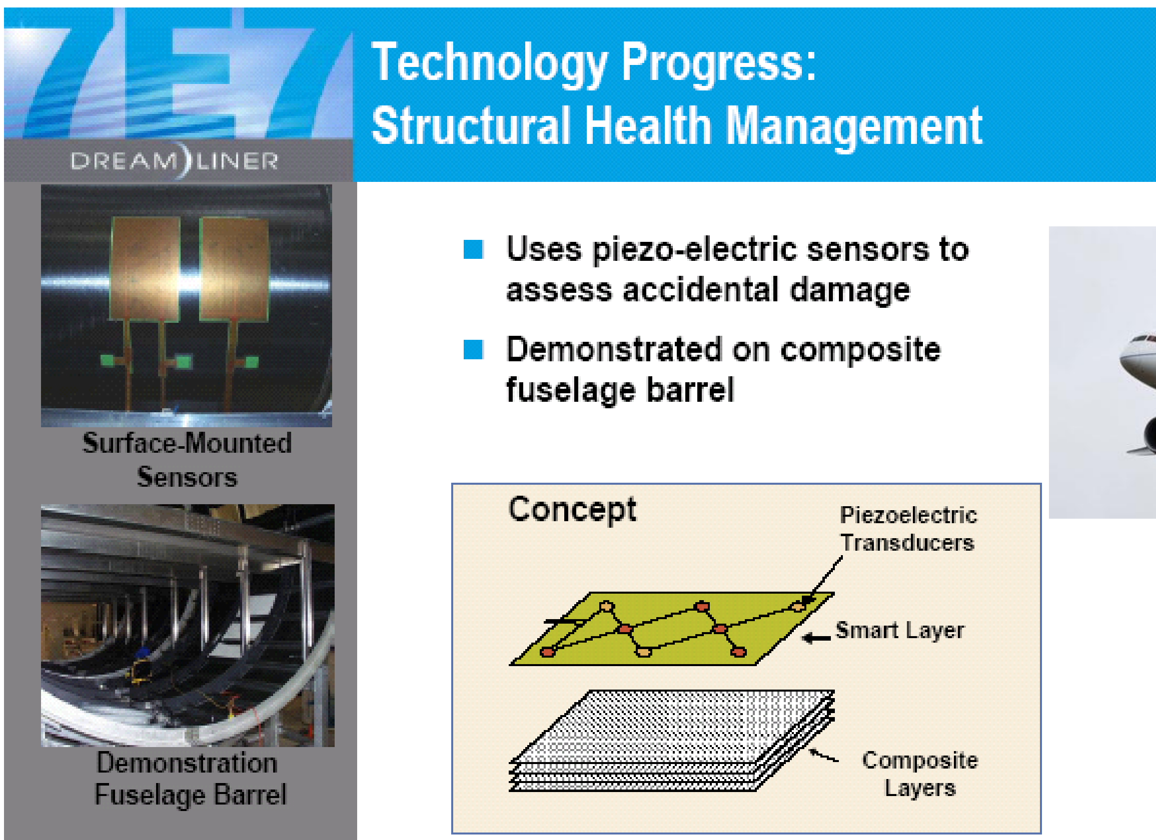




(Adapted from: Aerospace manufacturing website)

PIEZOELETRIC MATERIALS

Development of a methodology for the identification of damage in a real world complex aeronautical structure.
Structural health monitoring technique based on: impedance signals and meta-modeling.



Farnborough - July 20, 2010

Credits: Boeing

SMART MATERIALS AND STRUCTURES IN BRAZIL

Researchers

- **Search Lattes “estruturas inteligentes”: 867 researchers**
- **Busca Lattes “materiais inteligentes” : 994 researchers**

em (20/04/2018)

Research Groups

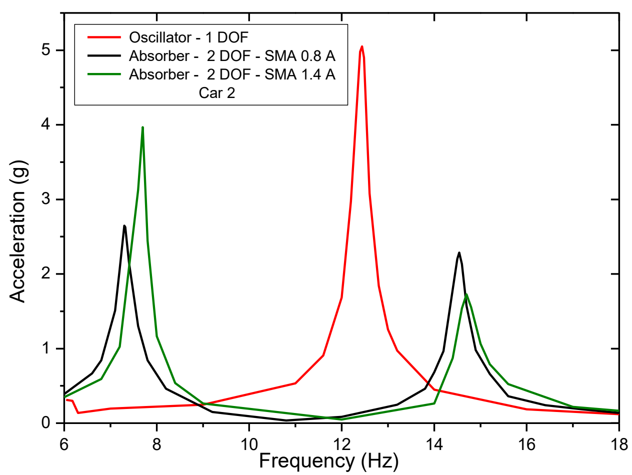
ITA, USP/Escola Politécnica, USP/EESC, UnB, FEIS/UNESP, UFRJ/COPPE, UFMG, PUC-Rio, UNICAMP, UFSC, UFPB, UFU, ...

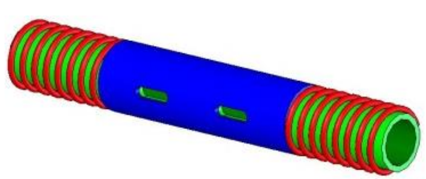
SMART MATERIALS AND STRUCTURES IN BRAZIL

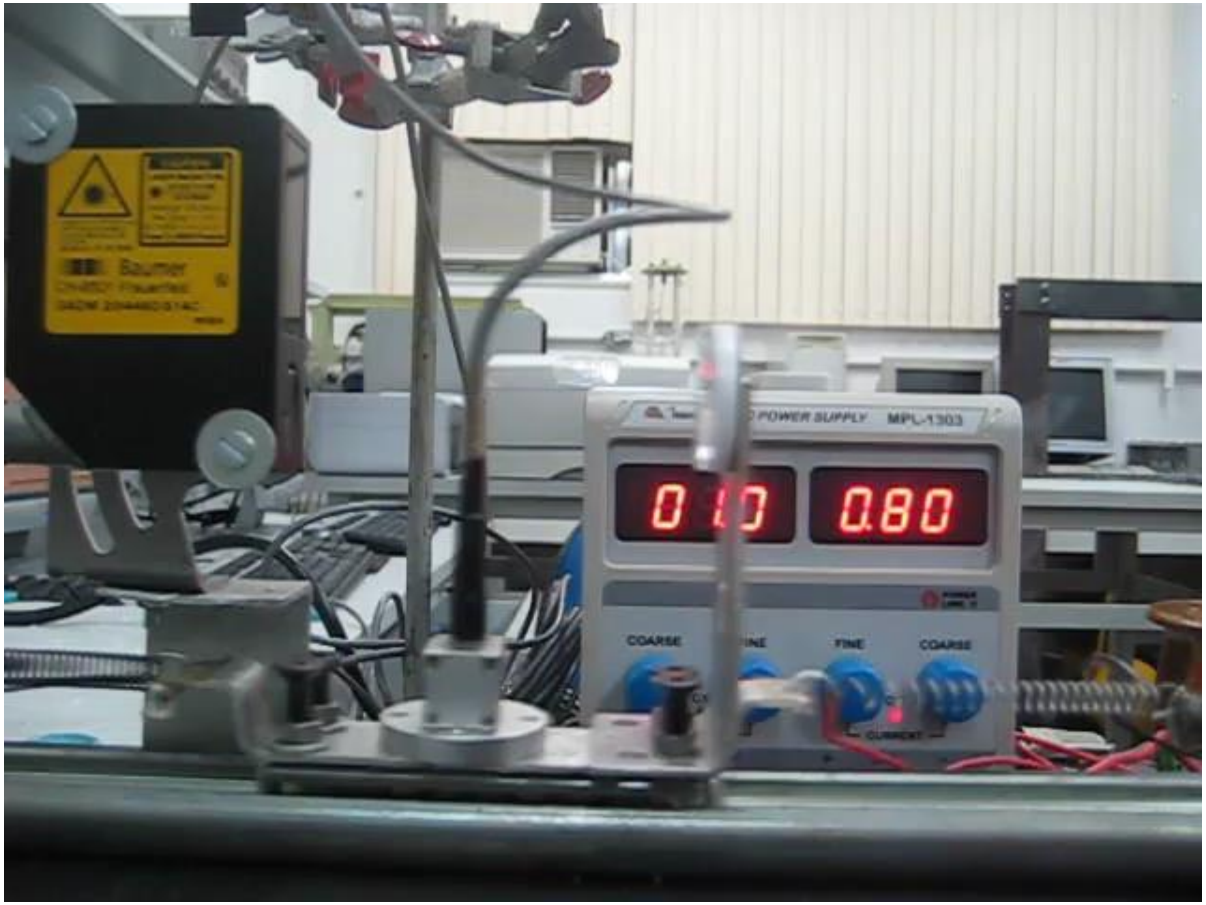
(COPPE-UFRJ) Laboratório de Acústica e Vibrações

SUB-PROJECT:
Shape Memory Alloy Structures: Manufacturing, Characterization, Modeling and Applications

Coordinator: ***Prof. Marcelo A. Savi***
Prof. Aline Souza de Paula **(UnB)**







SMART MATERIALS AND STRUCTURES IN BRAZIL

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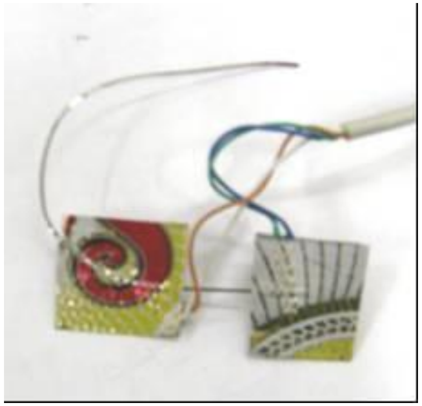
(UFCG) Multidisciplinary Laboratory of Active Materials and Structures (LaMMEA) - Prof. Carlos José de Araújo

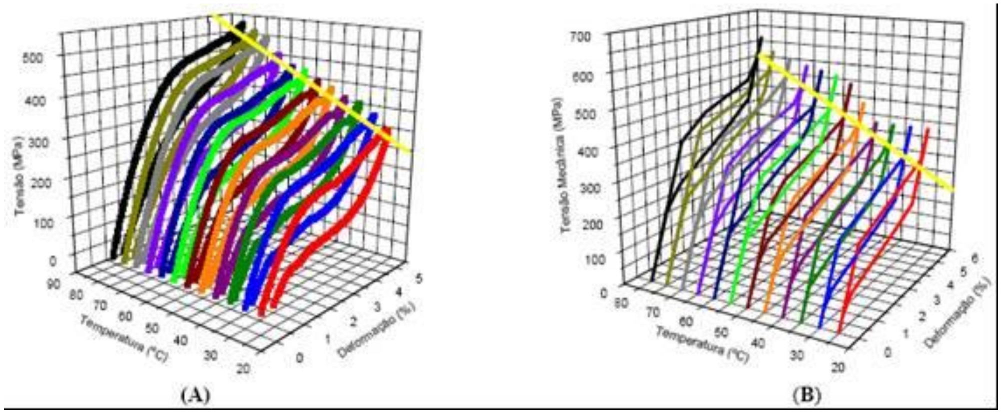
SUB-PROJECT: Development of SMA actuators and Thermomechanical Characterization

Shape Memory Alloy Structures: Manufacturing, Characterization, Modeling and Applications

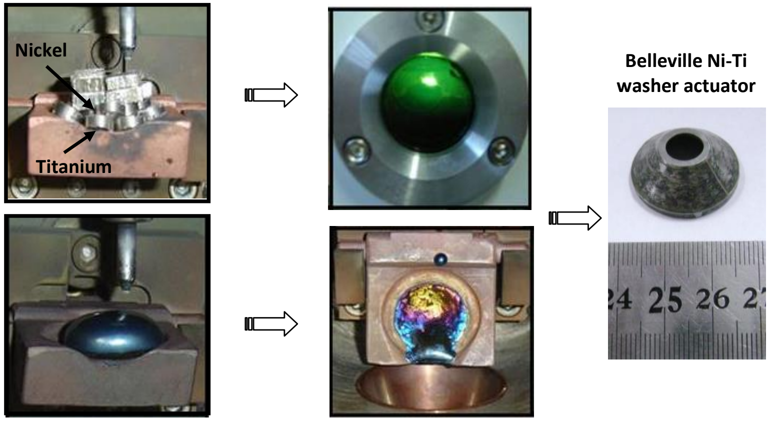
Ni-Ti SMA superelastic wires



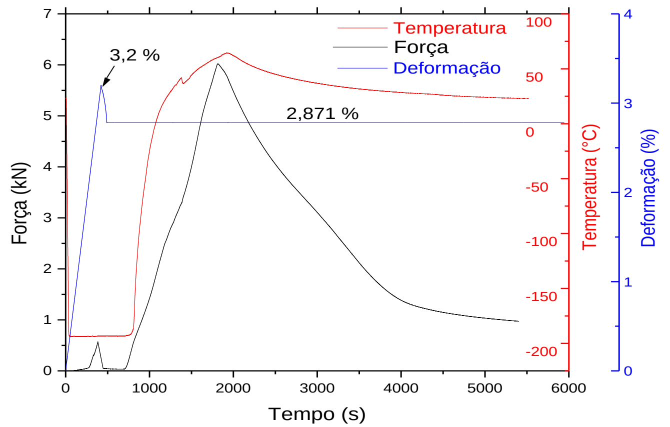
Experimental Stress-Strain Behavior / Simulation



Ni-Ti SMA Belleville washers



Experimental Force Generation



SMART MATERIALS AND STRUCTURES IN BRAZIL

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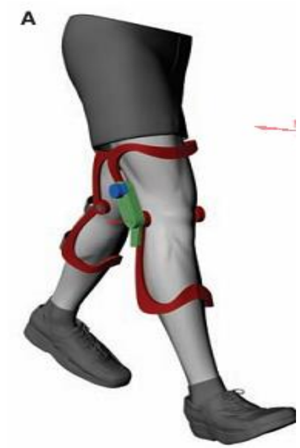
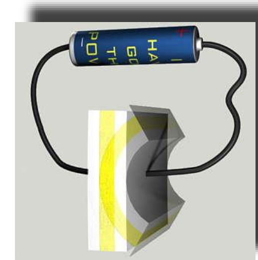
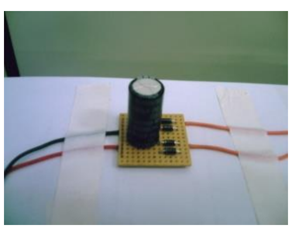
(UNESP-IS) GMSINT – Prof. Vicente Lopes Jr



Power harvesting





Electric power harvesting circuit

Piezoelectric material responsible for energy transformation

Micromechanics technology (MEMS) → wireless sensors; digital signal processors; low electric charge equipments

SMART MATERIALS AND STRUCTURES IN BRAZIL

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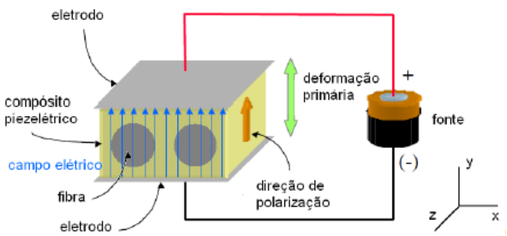
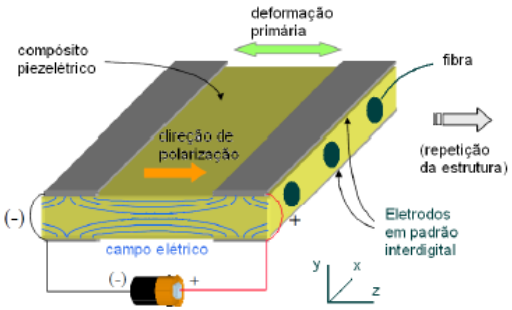
(USP-SC) Aeroelasticity Lab.

Coordinator: *Prof. Flávio D. Marques*

SUB-PROJECT:
Active/Passive Aeroelastic Control Via Active Fiber Composites (AFCs)

Technological innovations in active fiber composites (AFCs) applying in aeroelastic problems.
(I) Mathematical model of the mechanics of active fiber composites (AFC) and its validation
(II) active aeroelastic control laws for composite materials wings with incorporated AFCs
(III) study about passive AFCs as modal sensors applied to flutter prediction with the corresponding validation in a wind tunnel.





SMART MATERIALS AND STRUCTURES IN BRAZIL

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(USP-SC) Aeroelasticity Lab.

Coordinator: *Prof. Carlos De Marqui Jr.*

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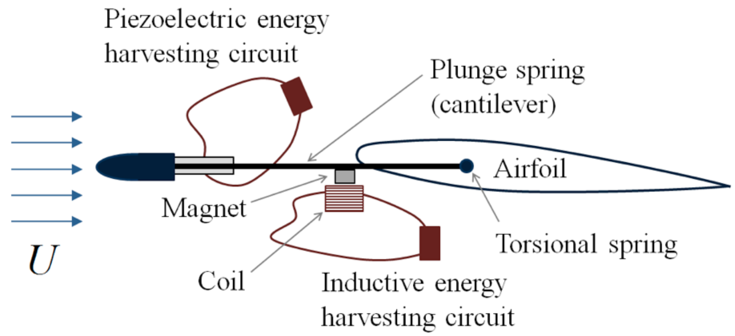
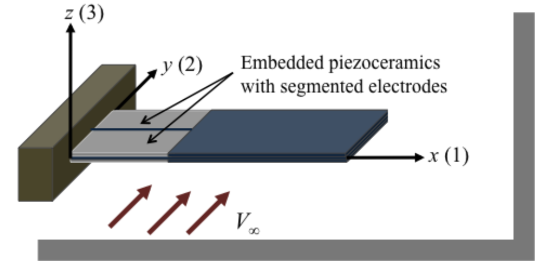
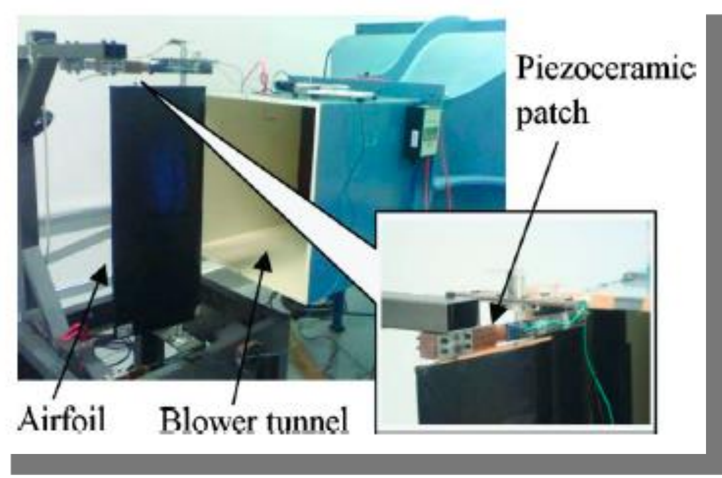
SUB-PROJECT:
Multifunctional Structures for Unmanned Air Vehicles





Energy Harvesting using piezelectric materials

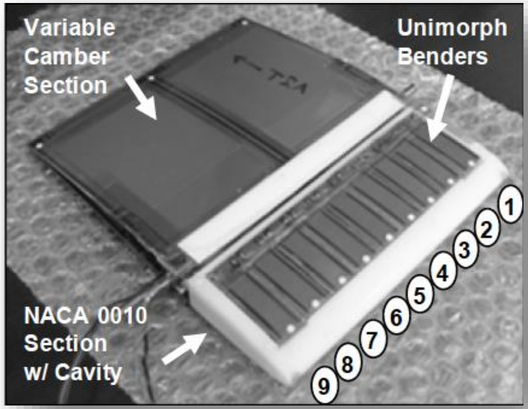
- ***Motivation***: provide power to low energy consumption of electronic systems
- Obtain energy sources to systems installed in remote areas (such as monitoring and security systems)
    - Provide energy to integrity structural monitoring of pipelines for gas and oil
- Convert vibration energy to electrical energy
- Convert flow energy to electrical energy (piezoaeroelasticity)

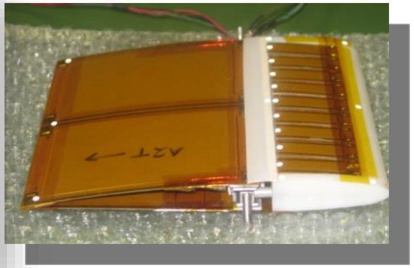


Morphing Airfoil **and Active Flow Control**

- Research motivation in this field is **active flow control using MFCs as actuators.**

- Benders (clamped beams covered with MFCs) are placed on the top surface of the airfoil.





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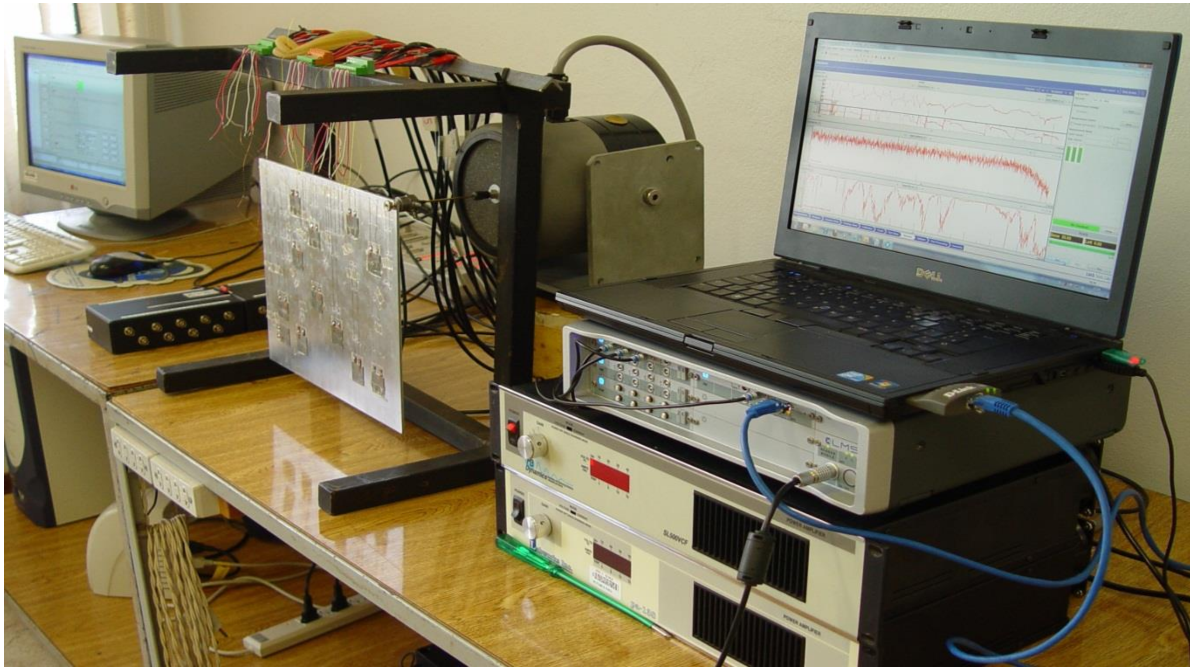
(USP-SC) Laboratório de Dinâmica

SUB-PROJECT:
Active and Passive Structural Vibration Control using Smart Materials

Coordinator: ***Prof. Marcelo Areias Trindade***

- Modeling of laminated structures containing piezoelectric materials connected to shunt circuits;
- Active, passive and semi-active vibration control techniques using piezoelectric materials;
- Development of modal sensors using piezoelectric materials for application in vibration control;
- Design and optimization of autonomous piezoelectric sensors.



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(ITA) Laboratório de Estruturas Inteligentes - LEICA

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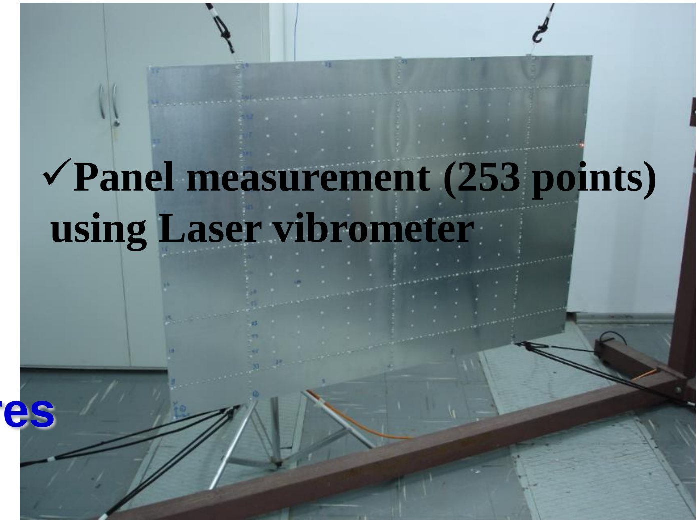
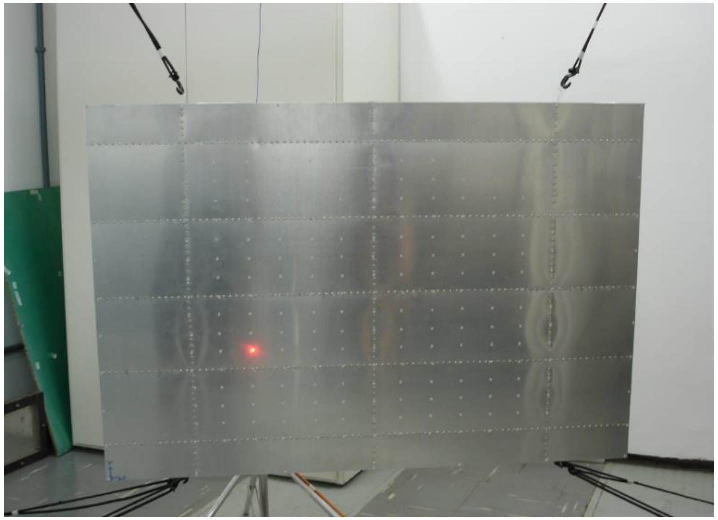
SUB-PROJECT:

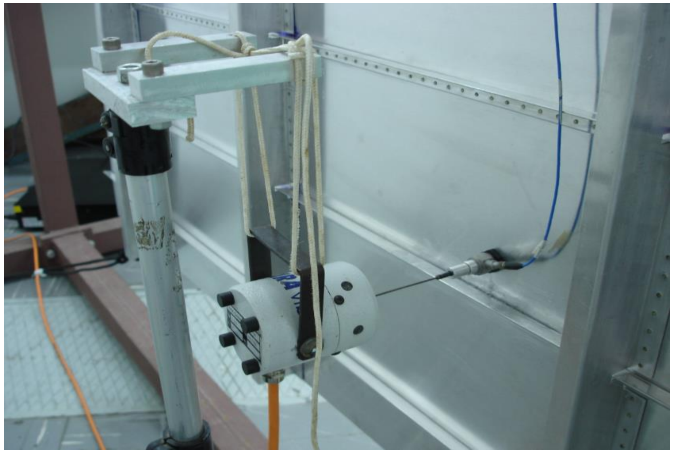
Smart Material Application in Aeroelastic Control

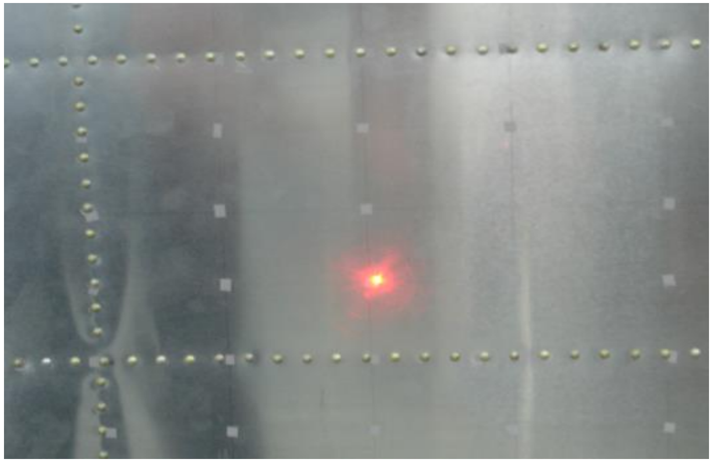
Coordinator: ***Dr. Roberto Gil Annes da Silva***

Shunt Damping of Smart Structures









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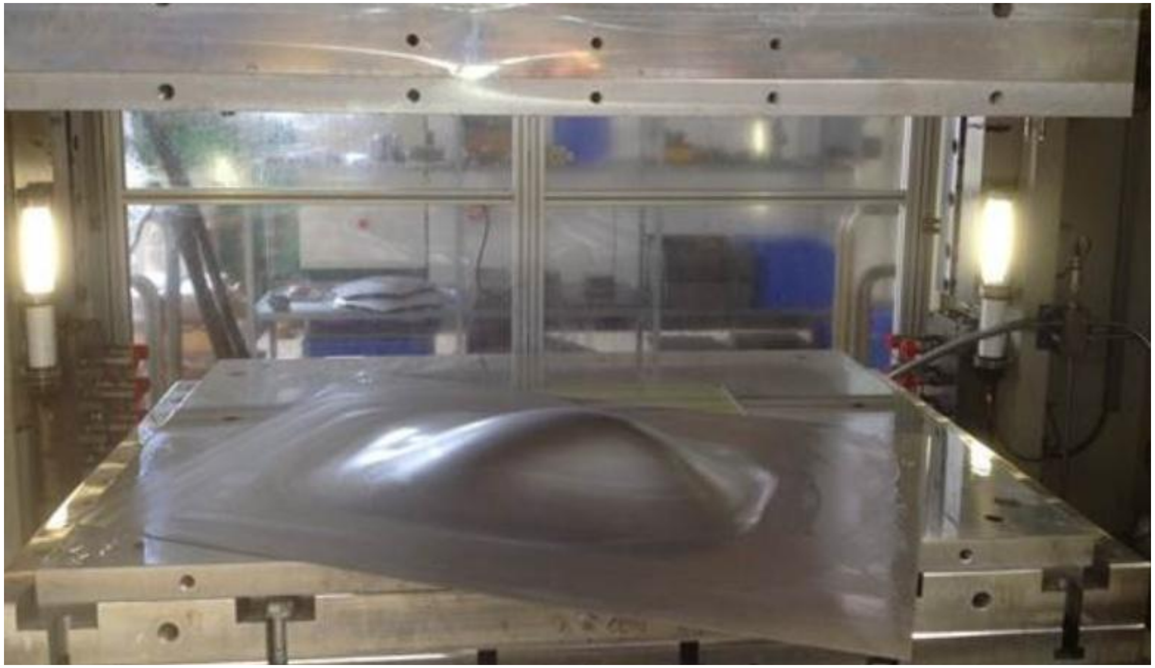
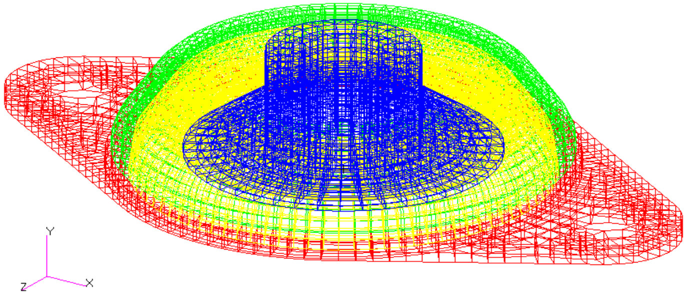
Finite Element modeling of the typical car cover panel including uncertainties

PZT application strategies.

Dynamic Analysis of Aerospace Vibration Isolators





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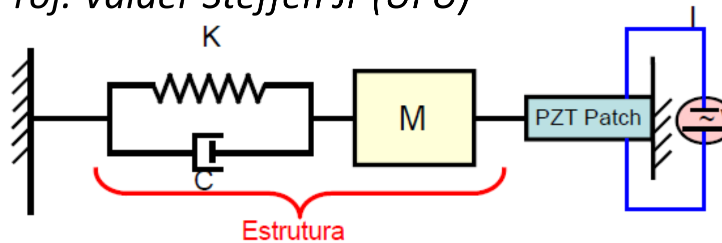
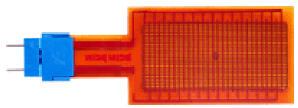
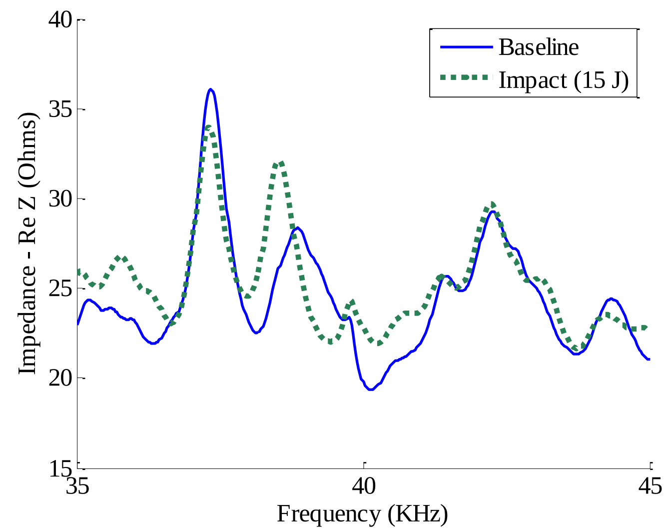
(UFU) Laboratório de Mecânica de Estruturas
Prof. José Eduardo Tannús Reis - LMEST

SUB-PROJECT:
Structural Health Monitoring Made of Composed Materials ; Smart Rotors

Coordinator: *Prof. Domingos A. Rade (ITA)*
Prof. Valder Steffen Jr (UFU)



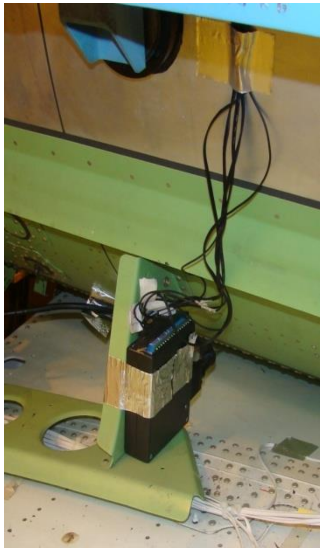


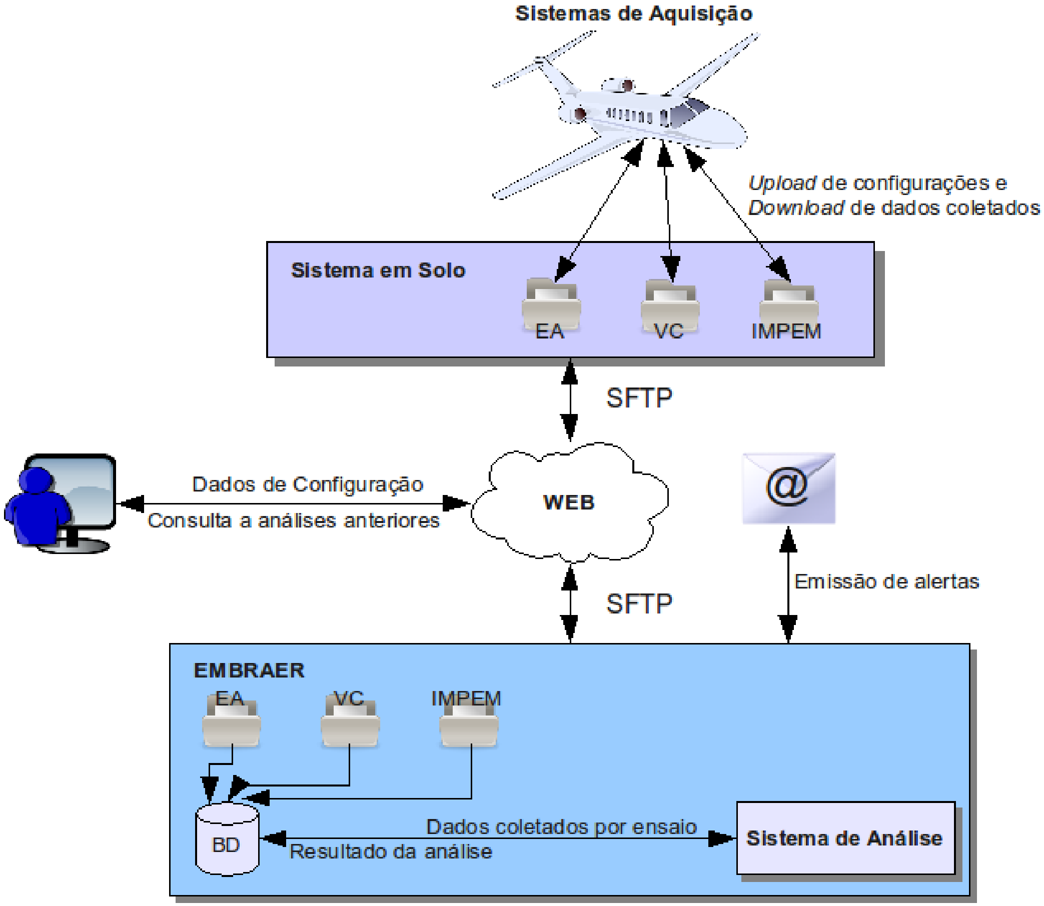


Damage Metric:

$$RMSD = \sqrt{\frac{\sum_{i=1}^{N}(\mathrm{Re}(Z_i^d)-\mathrm{Re}(Z_i^0))^2}{\sum_{i=1}^{N}(\mathrm{Re}(Z_i^0))^2}}$$

SMART MATERIALS AND STRUCTURES IN BRAZIL





Damage Detection in Concrete Prismatic Specimen

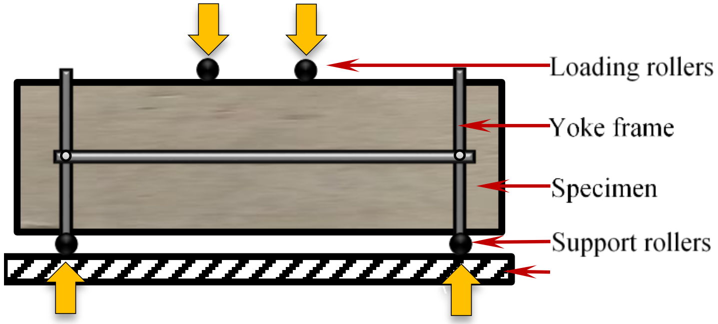
❖ **Prismatic Specimen:**

Length: 0.5 m; square section: 0.15 mm x0.15 mm

❖ **PZT patch:**

- Diameter: 0.03 m and thickness: 0.002 m.
- Two smart capsules were embedded in the prismatic concrete specimen

❖ Flexural Test Method for Flexural Performance of Fiber-Reinforced Concrete (Using Beam with Third-Point Loading)



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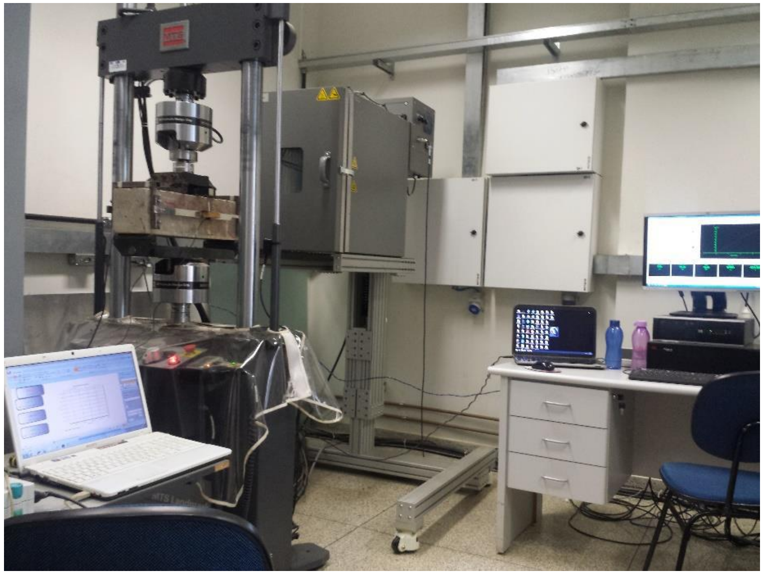

smart capsule

SMART MATERIALS AND STRUCTURES IN BRAZIL

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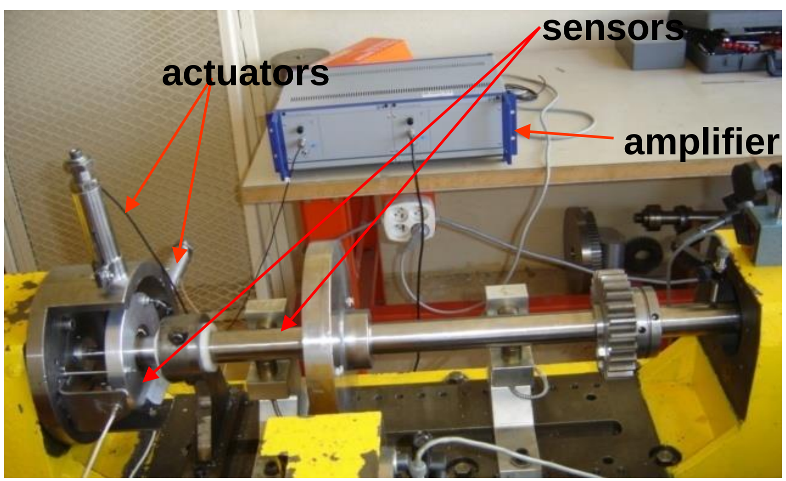
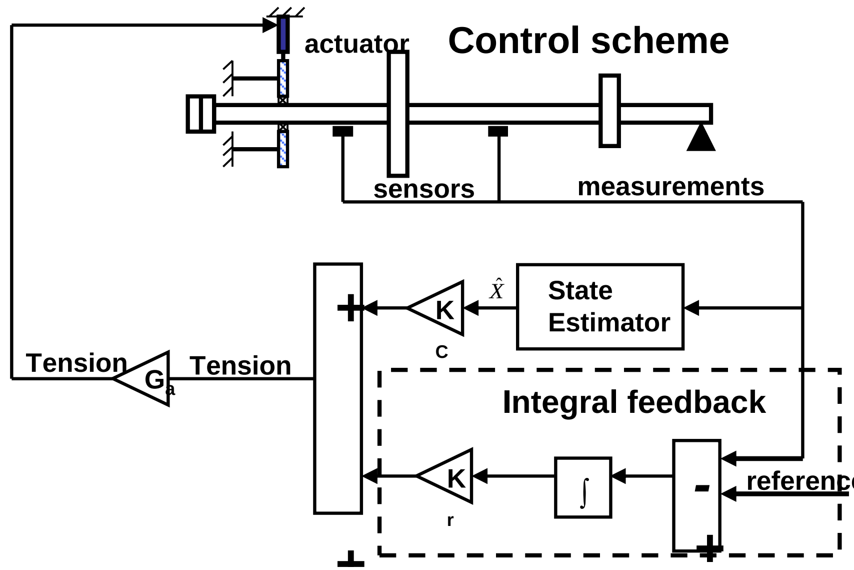
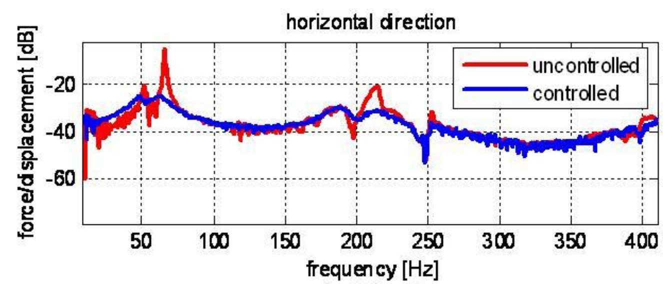
(UFU) LMEST SMART ROTOR TECHNOLOGY

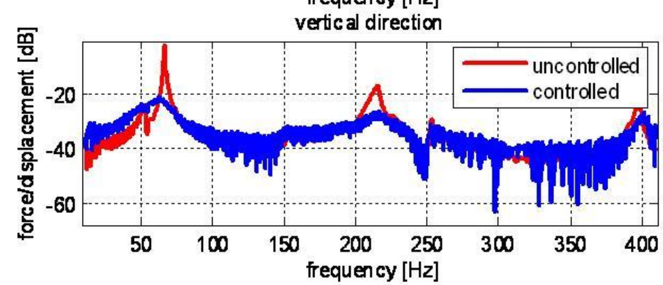
Data acquisition system



Control scheme



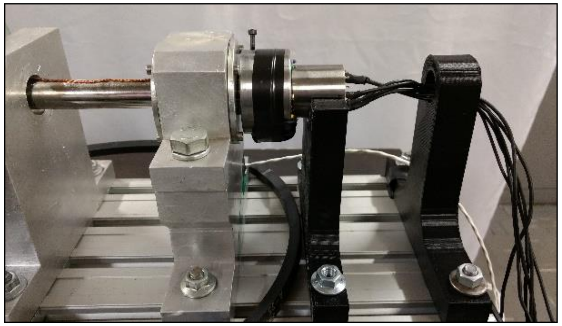


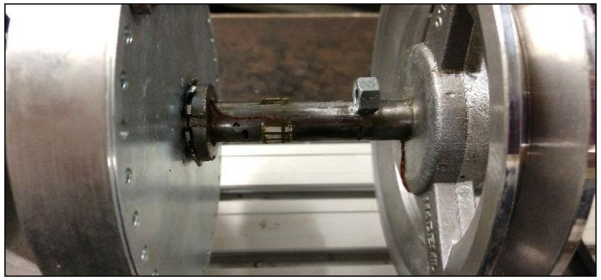


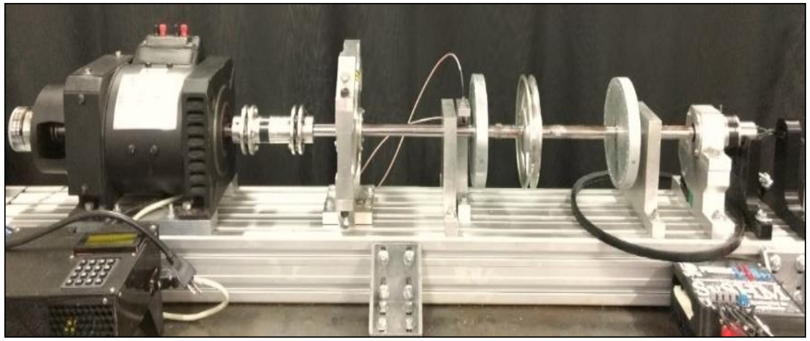
SMART ROTOR TECHNOLOGY

Measurement Devices:

- slip ring with ten circuit connections (Michigan Scientific's S-Series Slip Ring - C556019)
- Impedance measurement system (developed in our lab);
- The frequency range : [230 – 270] kHz.







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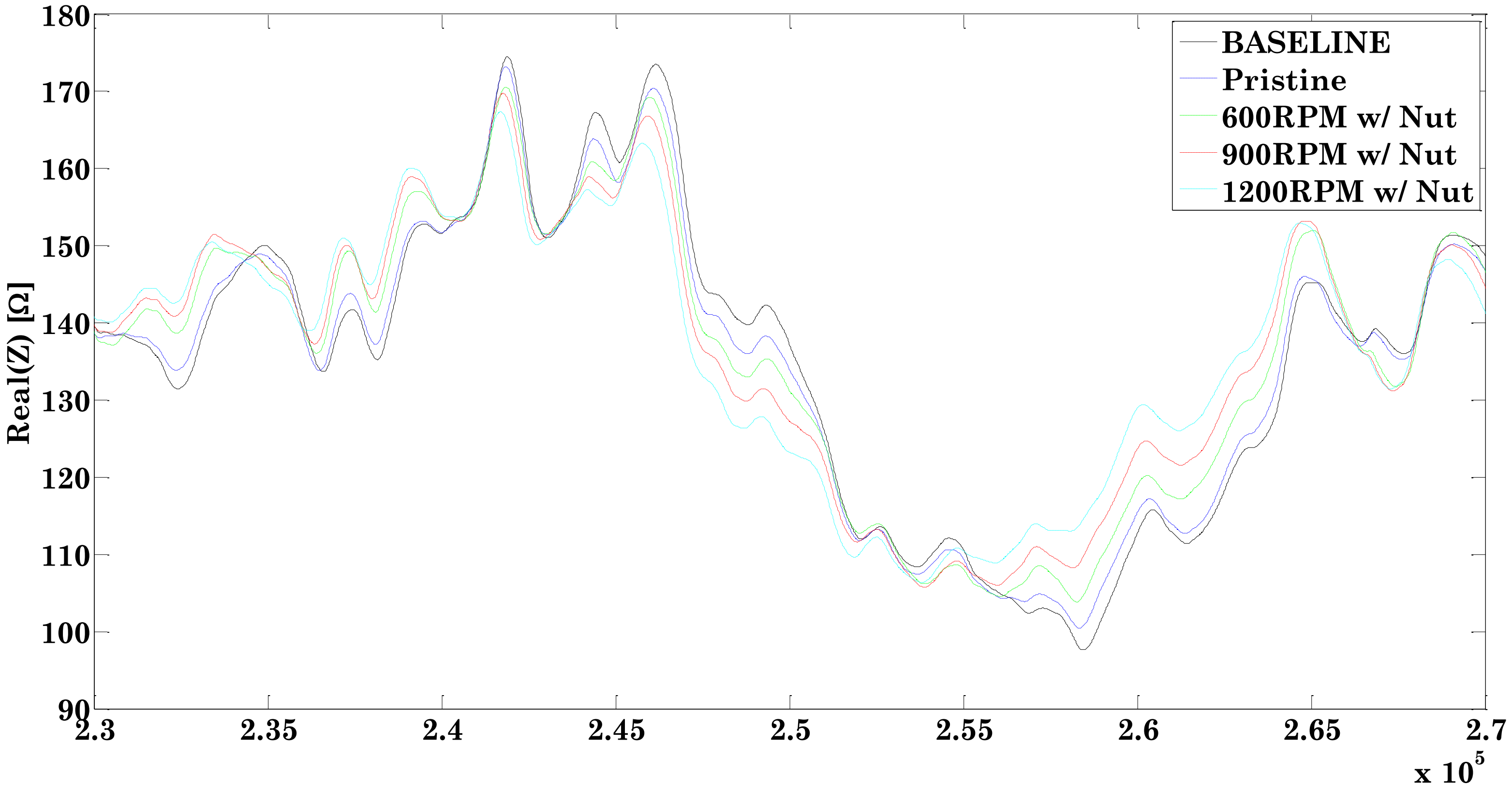

Electromechanical Impedance signatures

Recent patent

PI0311953-0 – Sistema de Acionamento de Transportadores Vibratórios por pastilhas piezelétricas.

Final Comments

- As a new technology, smart structures and materials require continuous research effort;

- As an interdisciplinary field, different skills and back-grounds are necessary for the research groups;

- Potential application in various engineering systems: aerospace and aeronautical structures, civil engineering constructions, motor vehicles, biomedical devices, etc.

- Some consolidated applications are found in the industry.

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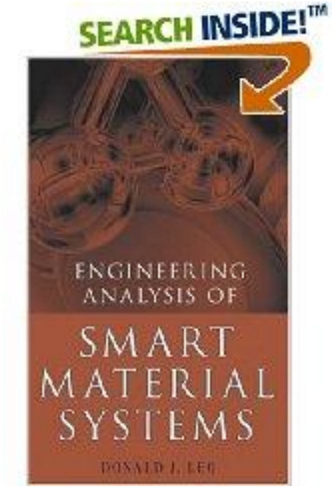
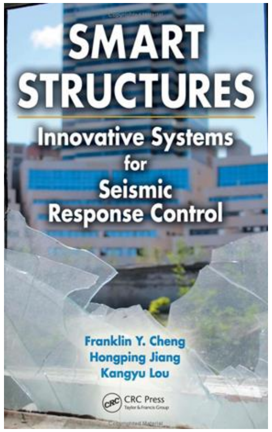
Final Comments

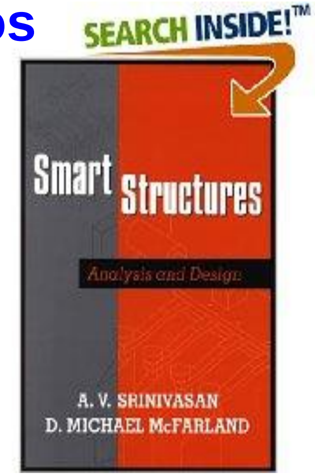
Livros



Wiley, 2007

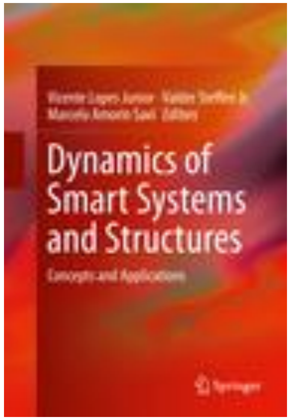


CRC Press, 2008



Cambridge
Univ. Press 2000

Springer, 2015



Springer, 2016

Year Chapter Downloads:
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2016 3,733
Total: 7,336

Springer, 2017

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Final Comments

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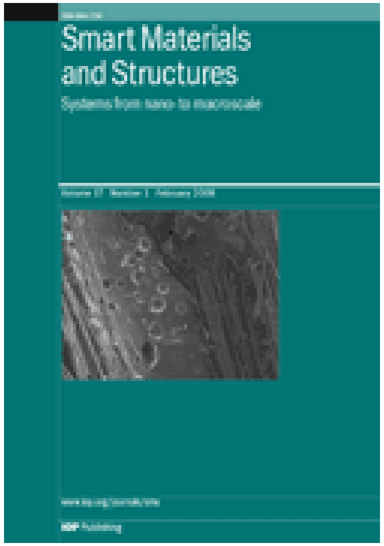
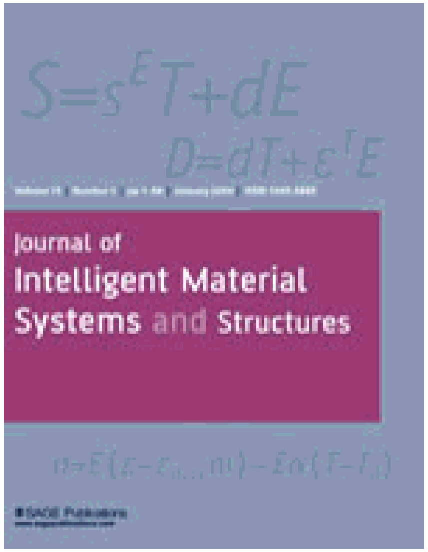
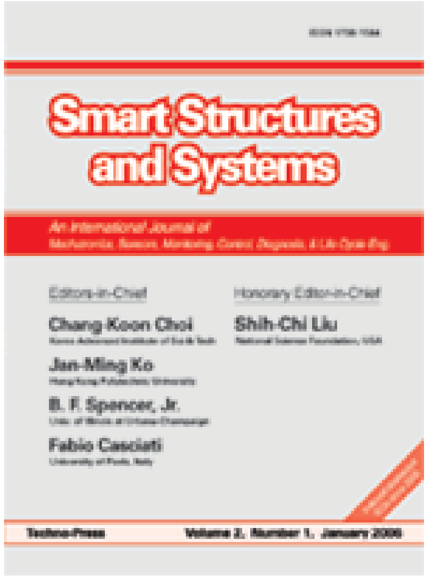
International Journals







Research activities

	TITLE	SUB-PROJECT COORDINATOR
1	Shape Memory Alloy Structures: Manufacturing, Characterization, Modeling and Applications	Prof. Marcelo A. Savi (UFRJ)
2	Robust Control and Power Harvesting using Smart Materials	Prof. Vicente Lopes Jr. (FEIS)
3	Aeroelastic Active/Passive Control via Active Fiber Composites (AFCs)	Prof. Flávio D. Marques (EESC/AERO)
4	Multifunctional Structures for Unmanned Air Vehicles	Prof. Carlos de Marqui Jr. (EESC/AERO)
5	Active and Passive Structural Vibration Control using Smart Materials	Prof. Marcelo Areias Trindade (EESC/DIN)
6	Smart Material Application in Aeroelastic Control	Roberto Gil Annes da Silva (ITA)
7	Structural Health Monitoring of Metallic and Composite Structures; Smart Rotors	Prof. Domingos A. Rade (ITA) Prof. Valder Steffen Jr (UFU)

Coordinator: Prof.Valder Steffen Jr

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Contact e-mail:
Prof. Valder Steffen Jr - vsteffen@ufu.br

Thank you!

Materiais e Estruturas Inteligentes: estado da arte e perspectivas

(Smart Structures and Materials: state-of-the-art and perspectives)

Valder Steffen Jr

(vsteffen@ufu.br)

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