Grenoble, October 14th, 2015

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SCUOLA POLITECNICA E DELLE SCIENZE DI BASE
DIPARTIMENTO DI INGEGNERIA INDUSTRIALE E DELL'INFORMAZIONE

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Numerical characterization of Magnetostrictive response of GalFeNol samples for Energy Harvesting

SECONDA UNIVERSITÀ DEGLI STUDI DI NAPOLI (SUN)
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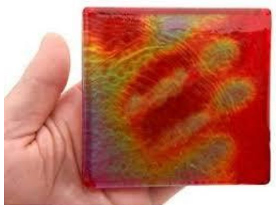
TEORESI S.p.A.
Claudio D'Avino

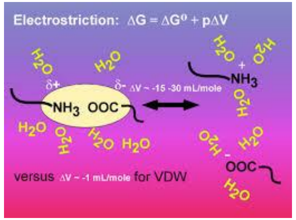
SMART MATERIALS

Smart materials are designed materials that have one or more properties that can be significantly changed in a controlled fashion by external stimuli.

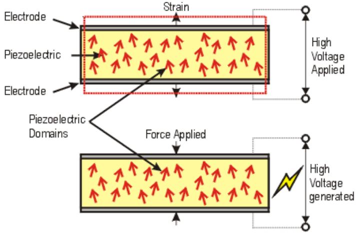


THERMOCHROMICS

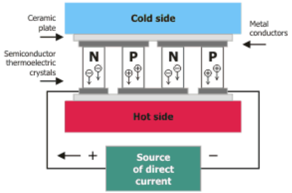
PHOTOCHROMICS



ELECTROSTRICTIVE



PIEZOELECTRICS

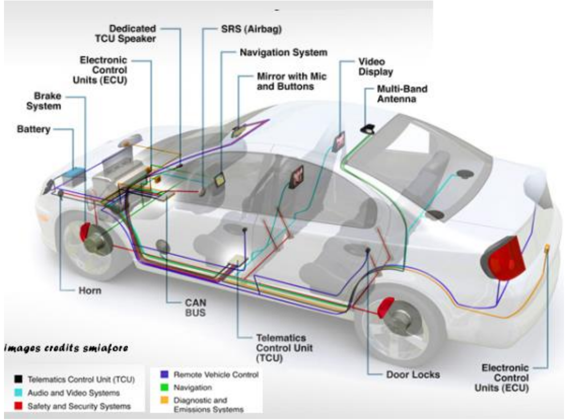


THERMOELECTRICS

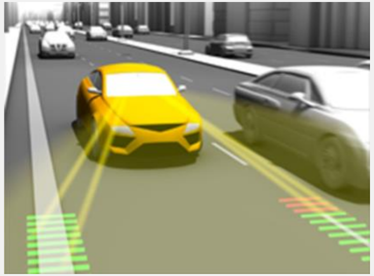
MAGNETOSTRICTIVES

APPLICATIONS IN AUTOMOTIVE of Smart Materials

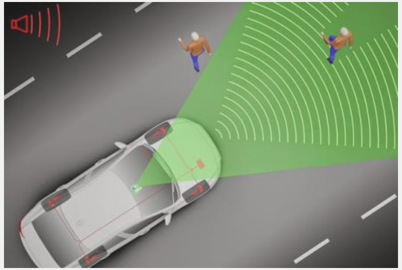
With the increasing of functions provided by vehicles, many of which are involved in active safety as ADAS, the number of information coming from the vehicle dynamic is growing fastly. These information (i.e Wheel speed, lateral and long acceleration, yaw rate) need to be delivered as fast as possible to the relative ECUs. Currently all these sensors are wired, this causes reliability and maintanance problems. Self powered wireless sensors can be the most effective solution.



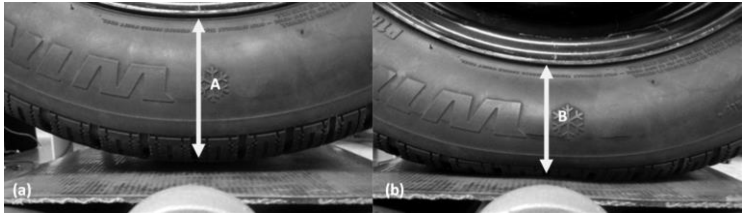
Lane Departure Warning



Forward collision mitigation

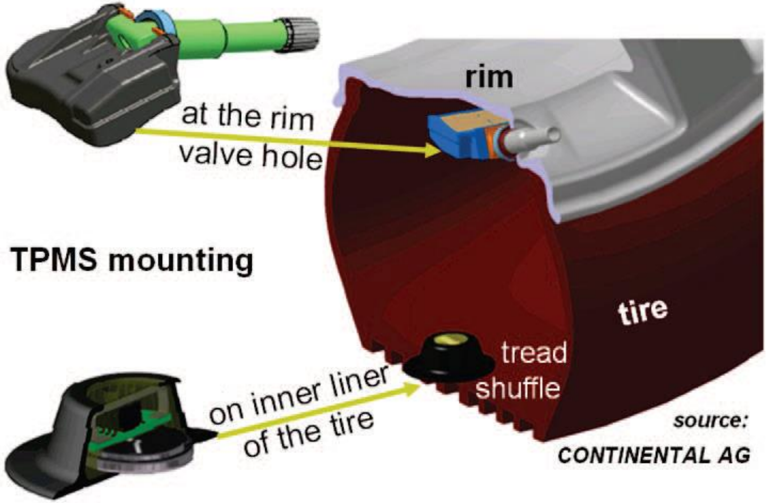


TIRE PRESSURE MONITORING SYSTEM (TPMS)



Innovative, energy autonomous sensors node have been already developed. The energy conversion was done by a MEMS-based piezoelectric vibration converter.

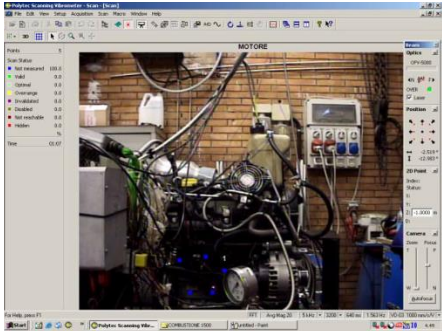
The data transmission is based on the IEEE 802.15.4 standard.

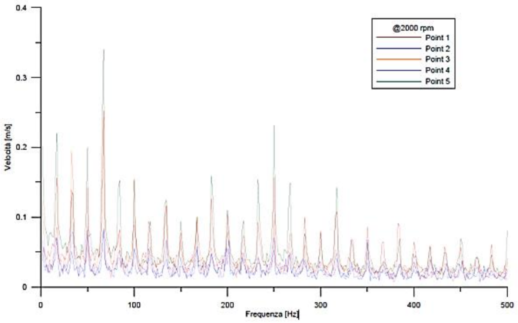


[**PIEZOELECTRIC POWER GENERATION IN AUTOMOTIVE TIRES**
Noaman Makki and Remon Pop-Iliev]

VIBRATION SOURCE IN THE VEHICLE

ENGINE

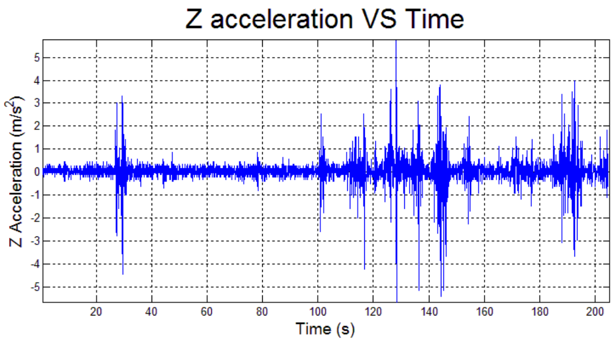


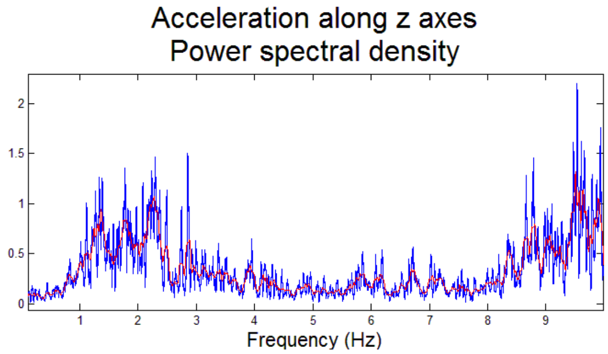


Most of vibrations comes from engine. A bench mounted four cylinders linear 1.7 L engine, as measured with dopler vibrometer (Polytec PSV-400), shows its maximum amount in vibration up to 500 Hz when it is running at 2000 rpm.

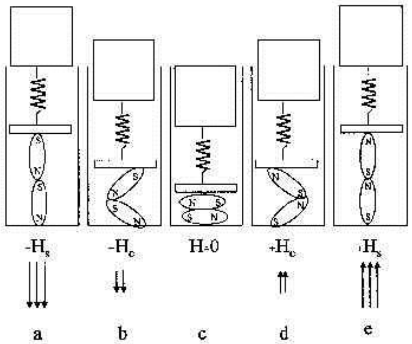
[**IMPIEGO DI TECNICHE MULTIBODY PER LA PREDIZIONE DELLA RADIAZIONE ACUSTICA** - Giacobbe Sabrina]

VEHICLE DYNAMICS





MAGNETOSTRICTION #1

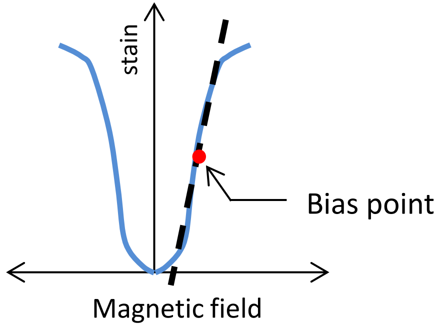


These vibrations can be recovered by using smart materials so as to provide power supply to wireless sensor in the vehicle so as to reduce the current big amount of cabling.

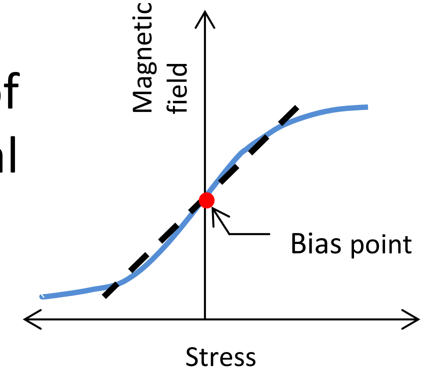
Magnetostriction occurs in most ferromagnetic materials and is due to Joule and Villari effects. The former is a transformation from electrical to mechanical energy, the latter is the reverse, i.e., mechanical stress drives magnetization the sample.

MAGNETOSTRICTION #2

Joule effect – Magnetostrictive materials exhibit free strain (λ) when exposed to magnetic field (H)



Villari effect – The magnetization (M) in this type of materials can be changed by applying mechanical stress (σ) in the presence of a bias magnetic field



TERFENOL-D VS GALFENOL

Property	Value	Unit
Density	9200	Kg/m^3
Young's modulus	30	GPa
Poisson's ratio	0,3	
Relative permeability	10	
Saturation magnetostriction	2000	ppm
Electrical conductivity	1,7*10^6	S/m
Ultimate Tensile Strength (UTS)	28	MPa

Terfenol: mechanical and magnetostrictive properties

Property	Value	Unit
Density	7800	Kg/m^3
Young's modulus	60	GPa
Poisson's ratio	0,3	
Relative permeability	80	
Saturation magnetostriction	400	ppm
Electrical conductivity	1,32*10^6	S/m
Ultimate Tensile Strength (UTS)	360	MPa

Galfenol: mechanical and magnetostrictive properties

In this study we are going to provide characterization either in mechanical and in magnetic terms of the innovative material GalFeNol.

USE OF COMSOL MULTIPHYSICS #1

Physics interfaces involved in the COMSOL model:

- Solids Mechanics;
- Magnetic Fields and Electrical Circuit.

Environment Mechanic:

- GalFeNol hollow and solid rod stressed by a time varying force directed on the longitudinal direction.

Environment Magnetic:

- Multiple wire coil and a resistive load to evaluate the electrical power generated by the energy harvesting.

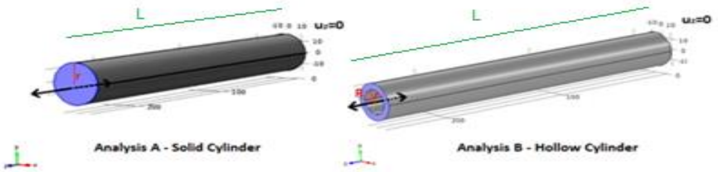
USE OF COMSOL MULTIPHYSICS #2

Constraint:

- uz=0 on one side.

Type of analysis:

- Parametric in frequency domain for both shapes (inner, outer radius r and height L)
- Sinusoidal peak force on other side of 1000 N;
- Number of turns of coil: 800;
- Resistive load of 100 Ω.



MATHEMATICAL MODEL

Equations mechanic/magnetic:

$$S_i = s_{ij}^T T_j + d_{ni}^T H_n$$

$$B_m = d_{mj} T_j + \mu_{mn}^T H_n, \qquad with \ i,j = 1, \dots, 6 \ and \ m,n = 1, \dots, 3$$

where s^T, d, μ^T are the tensors, piezomagnetic , permeability constant; S and T are the tensors of varying strain and stress, B and H are the vectors of varying induction and magnetic field.

Simplifying assumptions:

- transverse excitation fields are negligible (H1 = H2 = 0);
- radial stresses are equal to zero (T1 = T2 = 0) and there is no shear effect (T4 = T5 = T6 = 0),

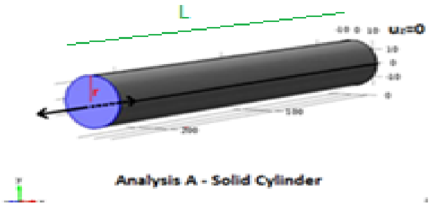
The longitudinal mode ('33' mode - zz mode) is obtained:

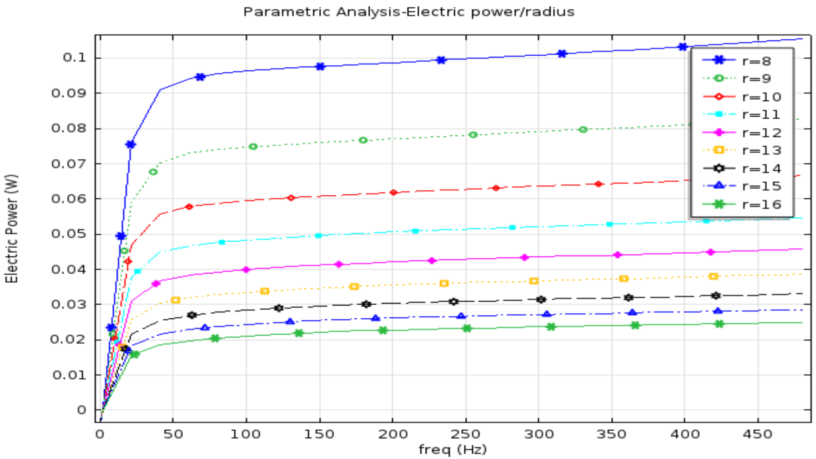
$$\varepsilon_{33} = \sigma_{33} T_3 + d_{33} H_3$$

$$B_3 = d_{33} \sigma_{33} + \mu_{33} H_3$$

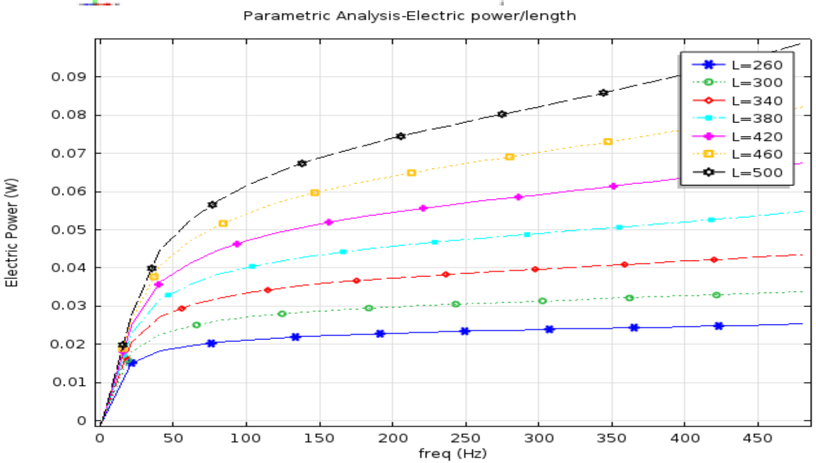
ANALYSIS A – SOLID CYLINDER

Frequency Domain: Electric Power-Radius/Length





with L=250 mm

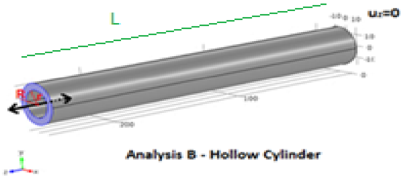


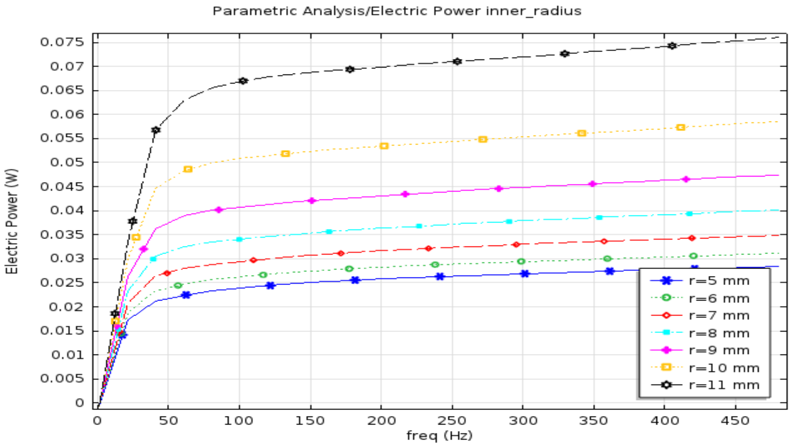
with r=16.5 mm

- Maximum stress $\sigma_{33} = 5.18$ MPa < 10% UTS = 360 Mpa;
- < Radius → > Electric Power;
- > Length → > Electric Power.

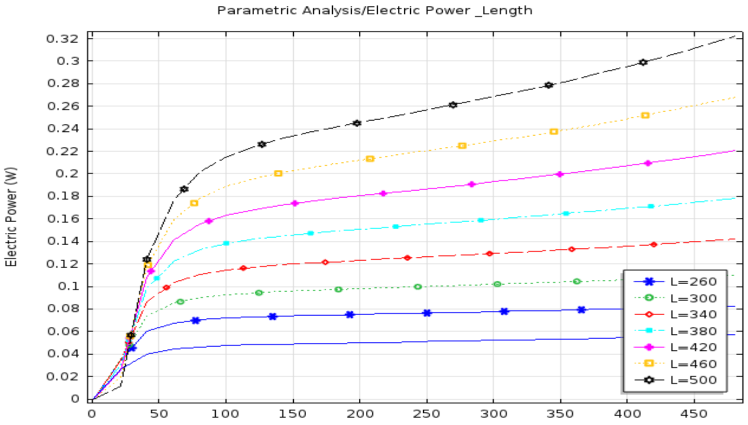
ANALYSIS B – HOLLOW CYLINDER

Frequency Domain: Electric Power-Inner Radius/Length





with L=250 mm, R=16.5 mm



with r=11 mm, R=16.5 mm

- Maximum stress $\sigma_{33} = 2.19$ MPa < 10% UTS = 360 MPa;
- > Radius → > Electric Power;
- > Length → > Electric Power.

TERFENOL-D GALFENOL VS

Frequency Domain: Electric Power for two materials (Solid cylinder)

Property	Value	Unit
Density	9200	Kg/m^3
Young's modulus	30	GPa
Poisson's ratio	0,3	
Relative permeability	10	
Saturation magnetostriction	2000	ppm
Electrical conductivity	1,7*10^6	S/m
Ultimate Tensile Strength (UTS)	28	MPa

Terfenol: mechanical and magnetostrictive properties

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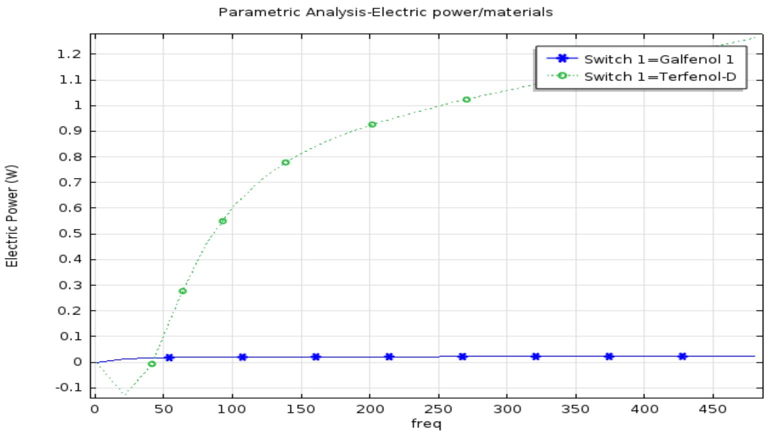
Galfenol: mechanical and magnetostrictive properties



CONCLUSION AND FUTURE STUDIES

- The results of the study show that GalFeNol is able to convert mechanical energy into electric one and at the same time to resist to mechanical stress. The maximum computed internal stress is below 10 % of UTS, i.e. even in the worst mechanical stress condition no permanent deformations happen.

- Future studies will deal with more complex 3D-models, taking into account the actual nonlinear behavior of such alloys, and more efficient electric circuits to improve energy conversion efficiency.

Any Questions?

COMSOL CONFERENCE 2015 GRENOBLE

THANK YOU for your attention!

Numerical characterization of Magnetostrictive response of GalFeNol samples for Energy Harvesting

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