POLITECNICO DI TORINO
ScuDo
Scuola di Dottorato ~ Doctoral School
WHAT YOU ARE, TAKES YOU FAR

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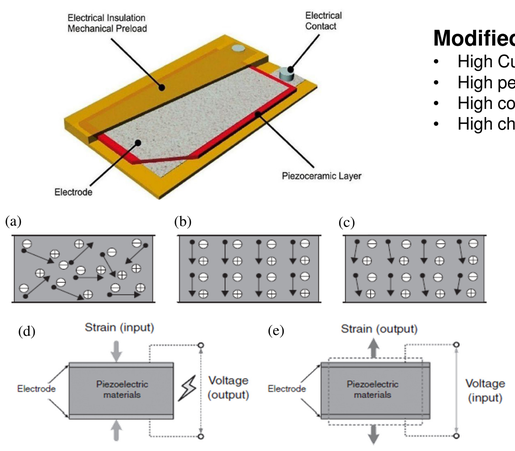
Tutor: **Ing. Massimiliana Carello**

27th September 2019
PhD Poster Day - XXXIII Cycle

Structural Health Monitoring System on a Smart and Lightweight Suspension Lower Control Arm

Bibliographic Research

Piezo Materials for Actuation/Sensing



Modified PZT material:
- High Curie temperature
- High permittivity
- High coupling factor
- High charge constant

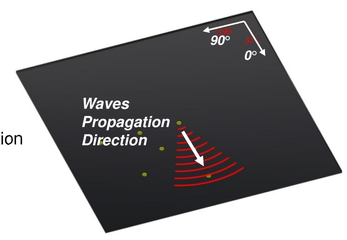
Poling operation:
(a) Random disposition of electrical dipoles
(b) External electrical field imposes a polarity direction
(c) Residual polarization ensures piezoelectricity

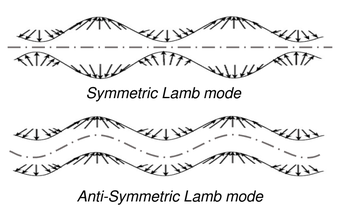
Principle of piezoelectricity:
d) Mechanical stress induces strain and voltage signal
e) Voltage signal induces mechanical strain and stress

Guided Lamb Waves in Thin Plates

Modes Parallel to Wave Propagation
- **Longitudinal (or dilatational, P)**
- **Rayleigh (or surface)**
- **Lamb (or plate)**
- **Stoneley (or interfacial)**

Modes Perpendicular to Wave Propagation
- **Shear (or transverse, S)**
- **Love**

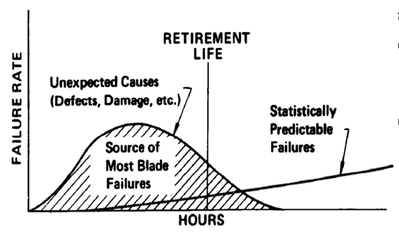




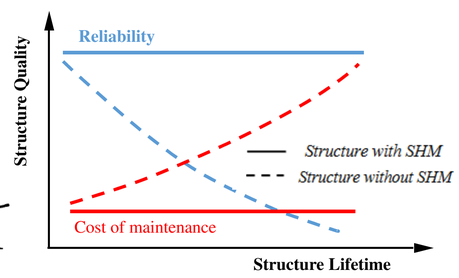
Lamb Waves depend on:
- Frequency
- Thickness of material
- Material type
- Structural geometry

SHM in Composite Structures

Damage detection and characterization could allow:
- Remote monitoring
- Programmed maintenance
- Preventive replacement



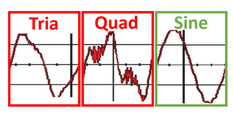
SHM on composite structures has great advantages:
- Reliability conservation
- Cost savings at long term

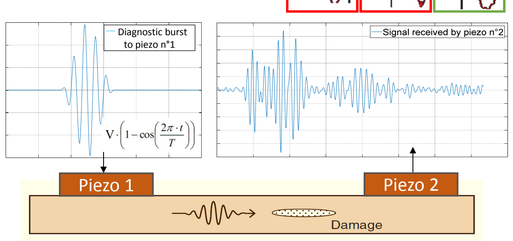


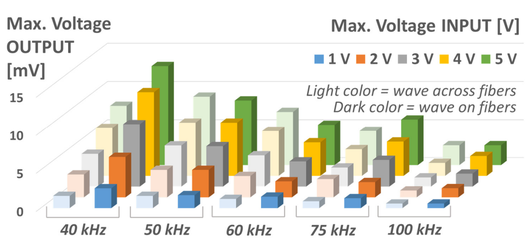
SHM System Setup

Pitch-Catch Method

Piezo behavior:
- Sinusoidal waves support
- Reduction of voltage amplitude

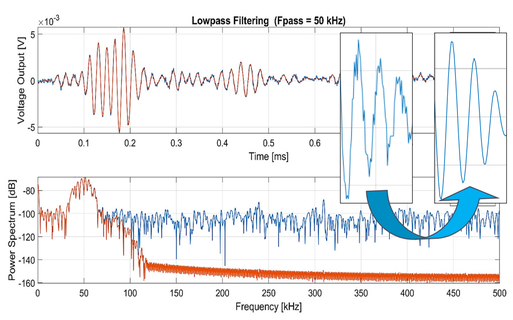






Data Filtering

Low pass filtering:
Keeps only the frequency lower then the Input frequency of Piezo 1



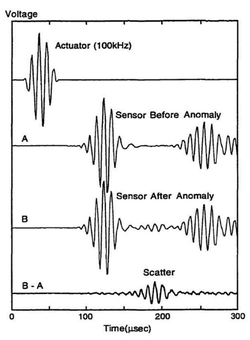
Number of samples:
- For each piezo couple have been acquired 5-10-100 samples
- Statistical Analysis via Hypothesis Test
- Understand the minimum number of samples to acquire in order to have a good confidence for the waves comparison

Piezo Couples for n=6, k=2

12				
13	23			
14	24	34		
15	25	35	45	
16	26	36	46	56

$\frac{n!}{k!(n-k)!} = 15$

Defect Detection



Waves comparison:

Damage Index $\rho = \frac{C_{XY}}{\sigma_X \sigma_Y}$

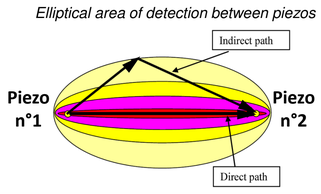
Covariance $C_{XY} = \frac{1}{K}\sum_{k=1}^{K}(X_k - \mu_X)(Y_k - \mu_Y)$

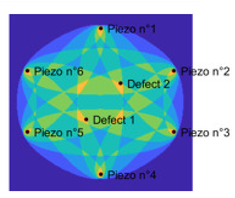
St. Deviation $\sigma_X = \sqrt{\frac{1}{K}\sum_{k=1}^{K}(X_k - \mu_X)^2}$

[by X.Zhao et al. (2007)]

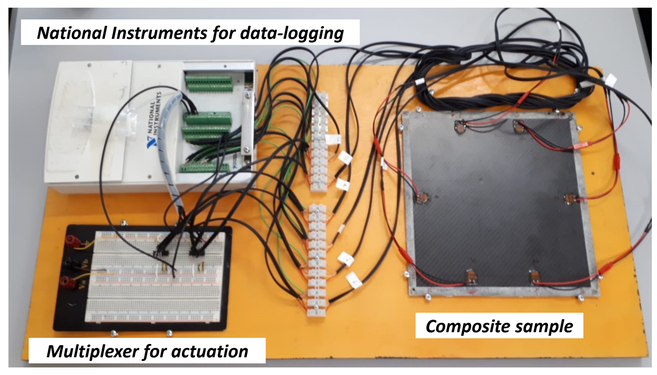
Defect Localization

Elliptical area of detection between piezos





Test Bench



National Instruments (NI 6259)

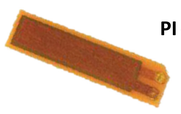
Analog Output	Analog Input
4 channels	**16** differential, **32** single handed
Max. ±10 V	**Max.** ±10 V
Resolution 16 bit	**Resolution** 16 bit
Sample Rate 2,86 Msamples/s	**Sample Rate** 1 Msamples/s

Multiplexer - MUX (TI CD74HC4052)

DC Supply
V_{CC} -0,5 to +7 V
V_{EE} +0,5 to -7 V
V_{CC}-V_{EE} -0,5 to +10,5 V

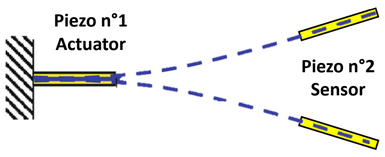
Case Studies: Beam & Plate Defect Localization

1) COMPOSITE BEAM
300 x 12 x 1 mm
3 Rectangular Piezo

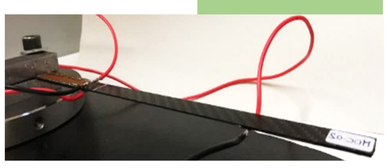


PI - DuraAct P876 K015
Piezo: 40 x 9 x 0,2 mm
Resonance: 150 kHz

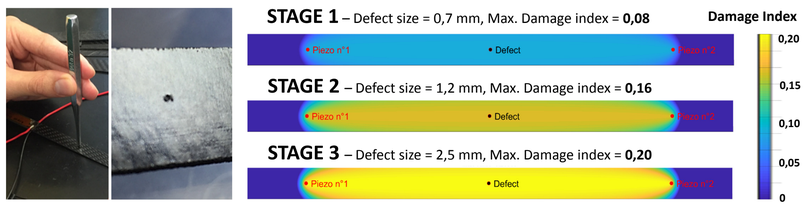
Objectives:
- Composite beam resonance at 17 Hz
- Epoxy resin bonding allows the maximum Voltage at 2 kHz
- Best acquisition frequency range at **40 kHz**
- Defect detection with SHM system



Fixed Beam



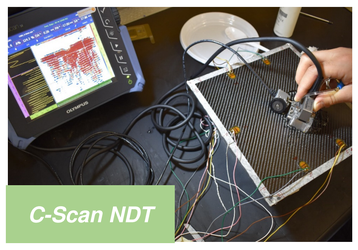
Damage: 1 defect, 3 stages



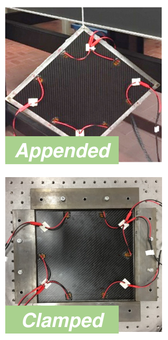
2) COMPOSITE PLATE
250 x 250 x 4,6 mm
6 Circular Piezo

PI - DuraAct P876 K025
Piezo: ϕ10 x 0,2 mm
Resonance: 150 kHz

Objectives:
- Best acquisition frequency at **60 kHz**
- Switching system actuation/sensing based on Multiplexer
- Defect detection
- Defect localization
- Stage identification
- Constraint effect on system results



Defect Dimensions
C-Scan ND Analysis



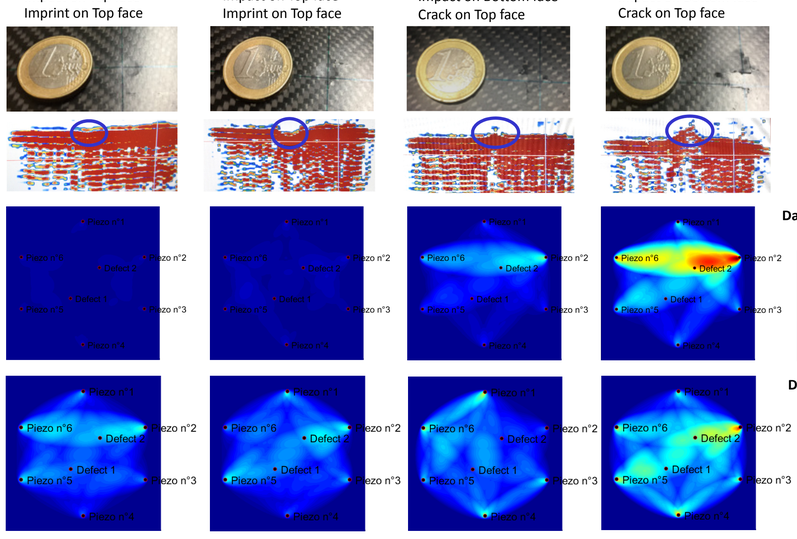
Damage: 2 defects, 4 stages

STAGE 1
Impact Energy = **5 J**
Impact on Top face
Imprint on Top face

STAGE 2
Impact Energy = **7 J**
Impact on Top face
Imprint on Top face

STAGE 3
Impact Energy = **5 J**
Impact on Bottom face
Crack on Top face

STAGE 4
Impact Energy = **12 J**
Impact on Bottom face
Crack on Top face

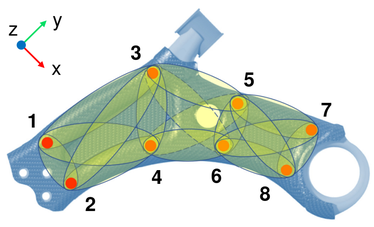


NEXT STEP: Component Application

Lower Control Arm (LCA)
for a Mc Pherson suspension

Multimaterial Design
- ***Steel substrate***
- ***Coupling material***
- ***Composite laminate***

Piezo Positioning

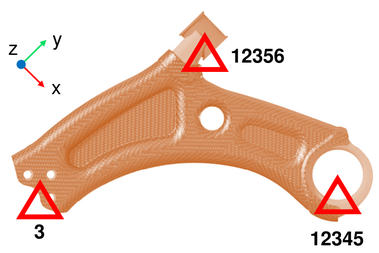


Interlayer:
- Delamination issues

Surface:
- Homogenous distribution

Ellypses optimization:
- Covering area vs. accuracy

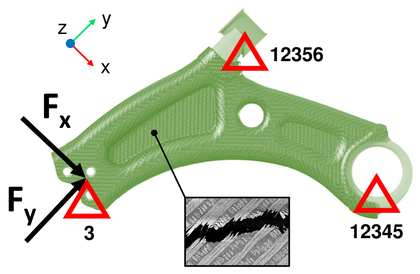
Constraints on Vehicle



Influence on SHM:
- FEM analysis of Lamb wave
- Sensitivity of SHM to static pre-loading on the constraints

Hybrid structures:
- Wave transmission through multimaterial

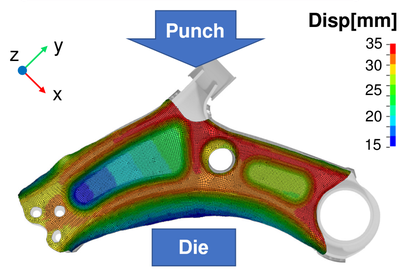
Damage Generation



Impact event:
- Dart geometry, potential energy

Fatigue stresses:
- Cycle number, frequency, amplitude
- FEM-EXP Correlation

Thermoforming process



Processability:
- FEM for Structural analysis and Mapping for textile shear angle
- Increasing production and reducing industry wastes

2nd Year PhD Activities

Academic Activities
- *Esercitazioni - **Chassis design B** (7 hours), Master Course of Automotive Engineering*
- *Esercitazioni - **Meccanica delle Macchine** (37,5 hours), Bachelor Course of Biomedical Engineering*
- *Tutor - **Master Thesis Simone Reitano**, Aerospace Engineering*
- *Tutor - **Master Thesis Pasquale Antonazzo**, Materials Engineering*
- *Tutor - **Master Thesis Patrizio Locatelli**, Materials Engineering*
- *Tutor - **Master Thesis Thibault Poulain**, Mechanical Engineering, INSA Centre Val de Loire (Blois, France)*
- *Tutor - **Master Thesis Flavien Becker**, Mechanical Engineering, INSA Centre Val de Loire (Blois, France)*

PhD Courses
- *HARD Skills Course - **Giunzioni strutturali**: progettazione, processi e tecnologie (30 hours)*
- *SOFT Skills Course - **Time management** (2 hours)*

Conferences
- ***AVK-EATC "Potential of Thermoplastic Composites"** / 27-28 may 2019 (Wesel, Cologne)*

Research Projects/Companies collaborations
- ***Research Activity with Multitel Pagliero S.p.A**: "Correlazione numerico-sperimentale su materiali compositi" e "BRA.MA. – BRAcci e MArtinetto in fibra di carbonio".*
- ***Research Activity with SFC**: "Balestra trasversale in materiale composito per applicazioni automotive".*
- ***Research Activity with Sabelt**: "Analisi stato dell'arte sui materiali compositi green e riciclabili, caratterizzazione sperimentale di tali materiali compositi e supporto alla definizione di carte materiale per il calcolo".*

Published Papers

- *Statistical energy analysis sea: A correlation between virtual and experimental results* / Ferraris, A.; Messana, A.; **Sisca, L.**; Santoro, F.; Airale, A. G.; Carello, M. - 2nd International Conference of IFToMM-Italy, IFIT Cassino – 68 (2019), pp. 211-220.
- *Modeling and optimization of the consumption of a three-wheeled vehicle* / Carello, M.; Bertipaglia, A.; Messana, A.; Airale, A. G.; **Sisca, L.** - SAE World Congress Experience, WCX 2019 - Cobo Center, USA.SAE TECHNICAL PAPER - ISSN 0148-7191.
- *Specific Energy Absorption Evaluation on GFRP Laminate Plate by Optical, Thermographic and Tomographic Analysis* / Virgillito, E.; Airale, A. G.; Ferraris, A.; **Sisca, L.**; Carello, M. - EXPERIMENTAL TECHNIQUES - ISSN 0732-8818 - 43:1 (2019), pp. 15-24.
- *Design, optimization and manufacturing of an aluminum wheel rim for the IDRAkronos vehicle prototype* / Messana, A.; **Sisca, L.**; Getti, C. M.; Malvindi, A.; Ferraris, A.; Airale, A. G.; Carello, M. - COMPUTER-AIDED DESIGN AND APPLICATIONS - ISSN 1686-4360 - 16:4 (2019), pp. 733-741.
- *From design to manufacture of a carbon fiber monocoque for a three-wheeler vehicle prototype* / Messana, A.; **Sisca, L.**; Ferraris, A.; Airale, A. G.; de Carvalho Pinheiro, H.; Sanfilippo, P.; Carello, M. - MATERIALS - 12:3 (2019).
- *Nafion tubing humidification system for polymer electrolyte membrane fuel cells* / Ferraris, A.; Messana, A.; Airale, A. G.; **Sisca, L.**; de Carvalho Pinheiro, H.; Zevola, F.; Carello, M. - ENERGIES - ISSN 1996-1073 - 12:9 (2019), p. 1773.
- *Steering system of a low-consumption vehicle: From the dynamics analysis to the design of the wheel assembly* / Ferraris, A.; Messana, A.; Multari, D.; **Sisca, L.**; Airale, A. G.; Carello, M. - 2nd International Conference of IFToMM – 68 (2019), pp. 91-99.
- *Photoinduced Frontal Cationic Polymerization of Epoxy-Carbon Fiber Composites* / Sangermano M.; Antonazzo, I.; **Sisca, L.**; Carello, M. - Polymer International (2019) - Wiley Online Library.
- *Computational Analysis of Body Stiffness Influence on the Dynamics of Light Commercial Vehicles* / de Carvalho Pinheiro, H.; Messana, A.; **Sisca, L.**; Ferraris, A.; Airale, A. G.; Carello, M. - Advances in Mechanism and Machine Science (2019), pp. 3117-3126.
- *Torque Vectoring in Electric Vehicles with In-wheel Motors* / de Carvalho Pinheiro, H.; Messana, A.; **Sisca, L.**; Ferraris, A.; Airale, A. G.; Carello, M. - Advances in Mechanism and Machine Science (2019), pp. 3127-3136.