Università degli Studi di Ferrara

Department of Engineering Ferrara

Multi-axis vibration testing to increase test efficiency and realism

Prof. Emiliano Mucchi

"Présenté lors de la journée technique « Les essais multiaxiaux », à MBDA Bourges, le 28/11/2018, organisée par l'ASTE (aste.asso.fr), à l'invitation de la société Kilonewton (kilonewton.fr)"

Outline

- Dept. of Engineering Ferrara and Laboratory facilities
- Mono vs multi-axis excitation (numerical and experimental cases)
- Low vs high coherence (multi axial testing)
- Real life applications
- Conclusions

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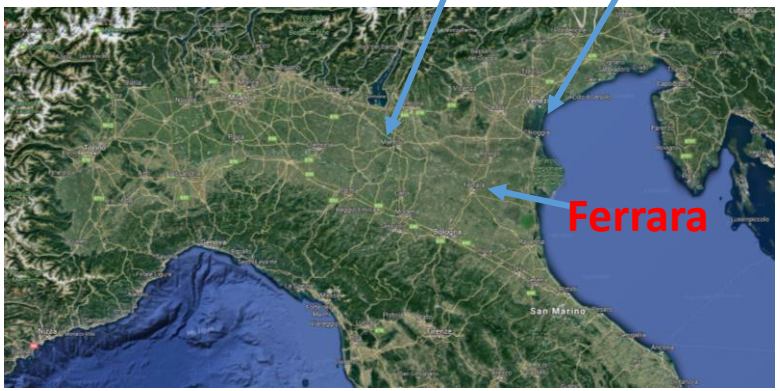

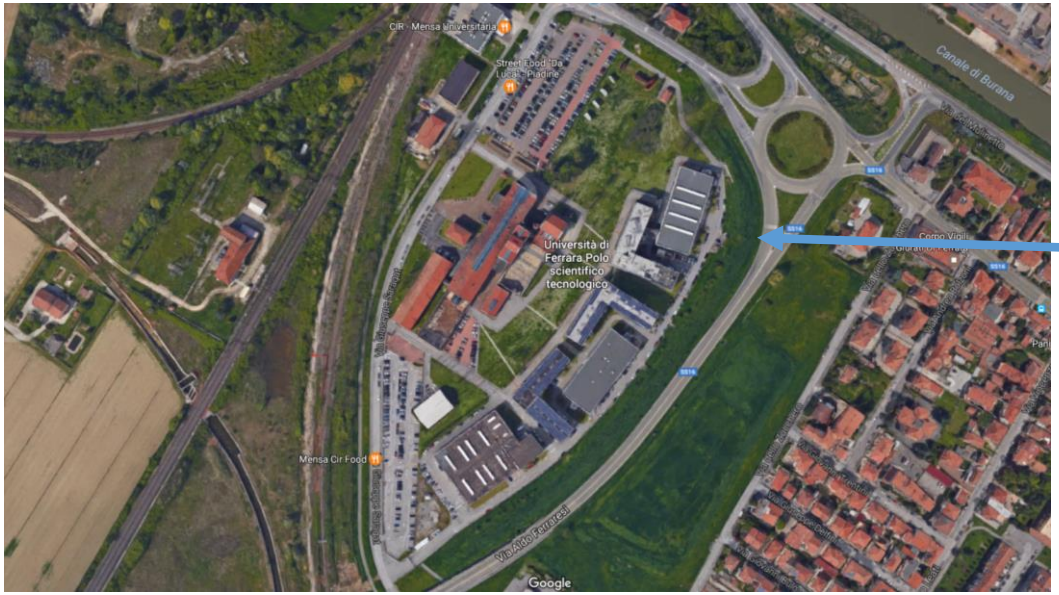

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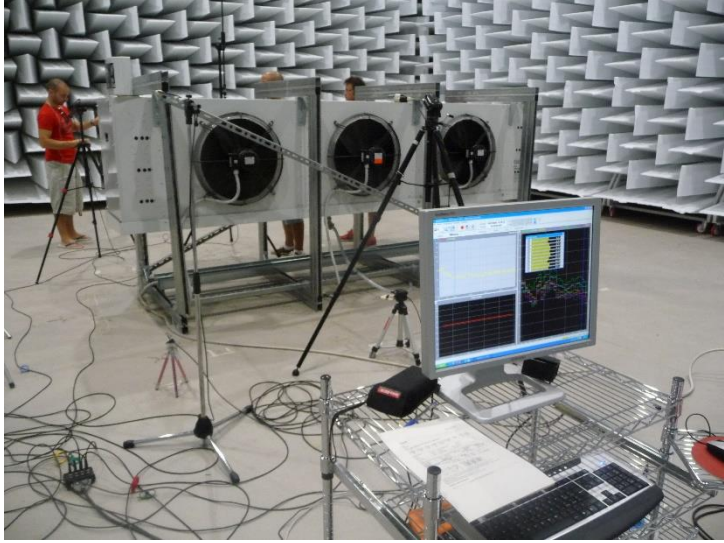
University of Ferrara (since 1391)

Lab Facilities



Anechoic and hemi-anechoic chamber
50Hz - >10kHz (10.1 x 9.5 x 8.3 m)

- Complete instrumentation for acoustic and vibration measurements and modal analysis
- MB, FEM, BEM software for simulation and optimization
- Model-Test correlation
- Test bench for rotating components (gears, bearings, joints)
- Laser Doppler vibrometers

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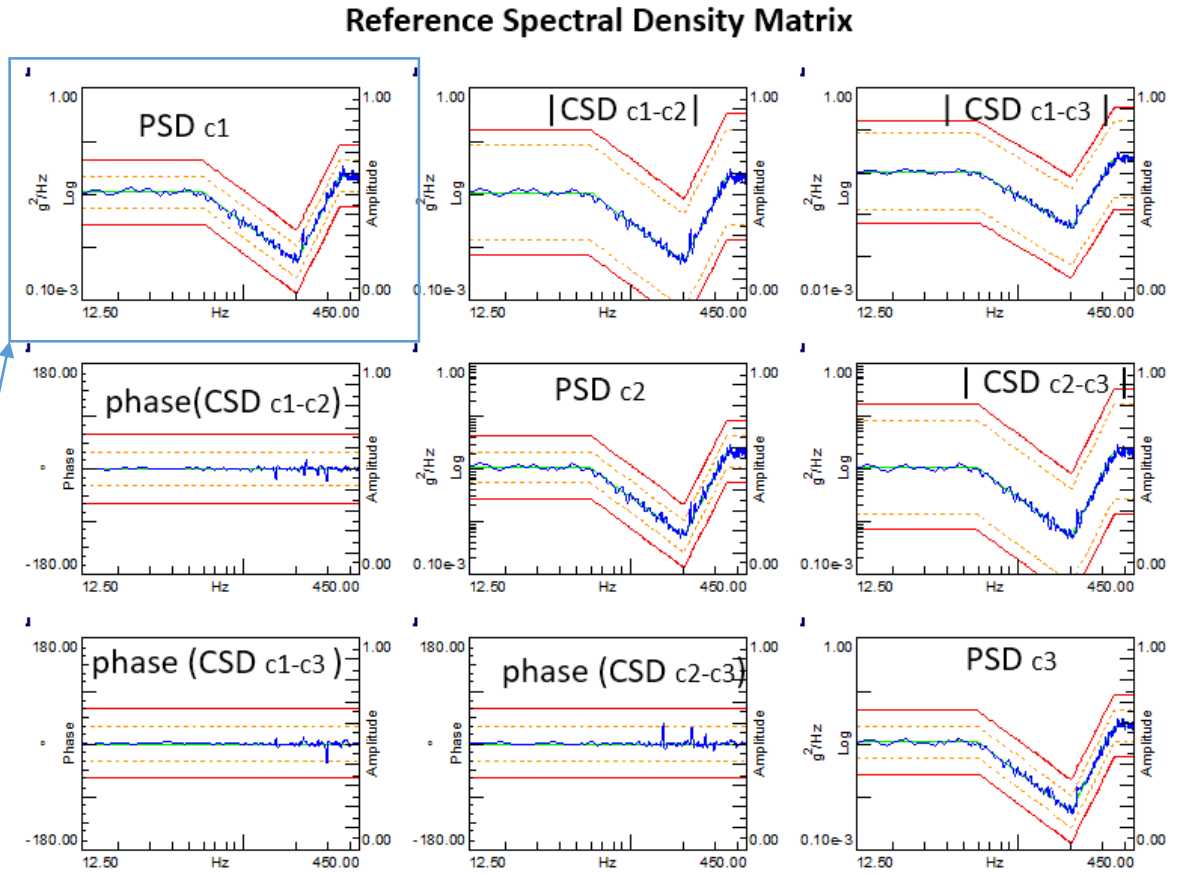
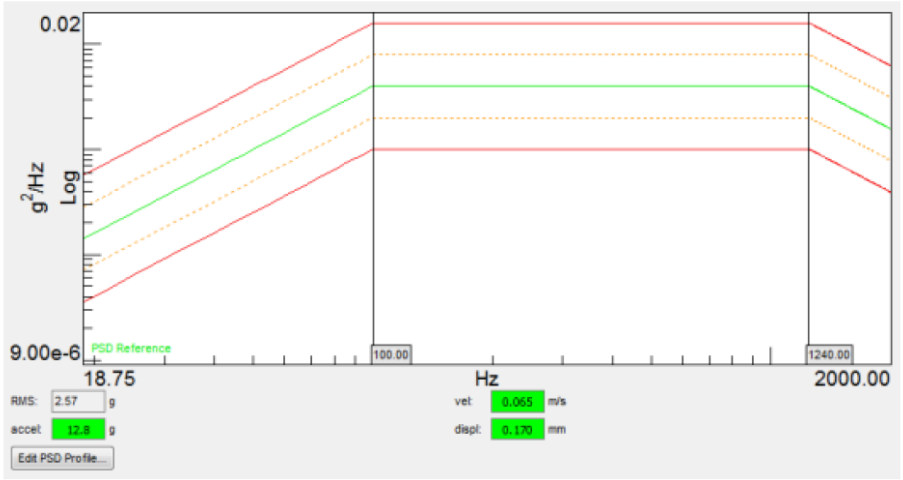
MIMO Random Control

The objective of a MIMO Random Control Test is to replicate a full Spectral Density Matrix. The diagonal terms of this matrix are usually known levels (Power Spectral Densities, PSDs) for the environmental test engineer, provided as test specifications. The off-diagonal terms are representative for the cross-talk between the control channels (Cross Spectral Densities, CSDs).

Single axis test Specification





Numerical analysis
Single vs Multi-axis excitation

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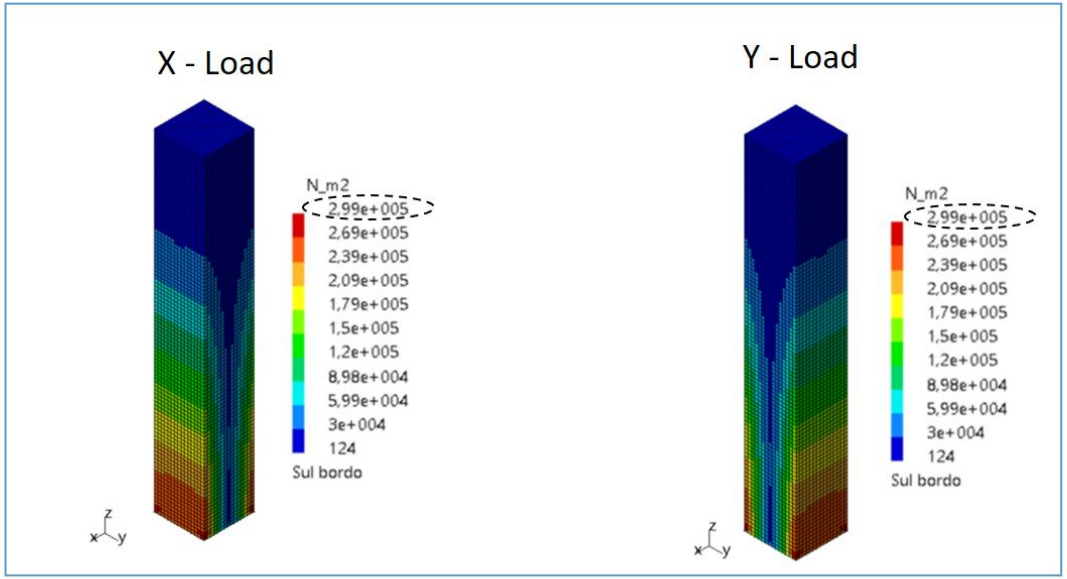
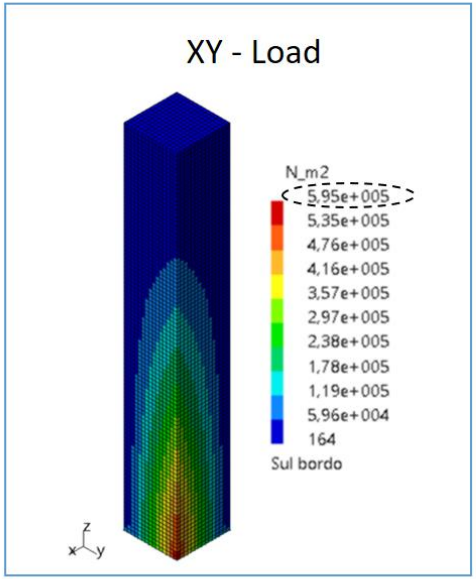
Max Stress for Single Axis Inputs



Max Stress for simultaneous Axis Inputs



stress occurs at different locations and with different magnitude

Numerical analysis
Single vs Multi-axis excitation

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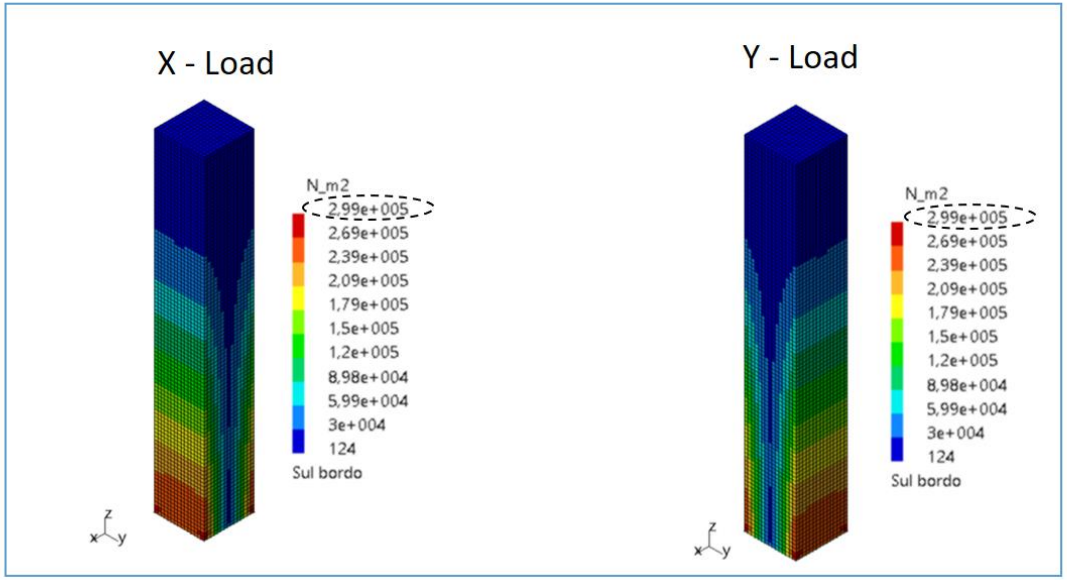
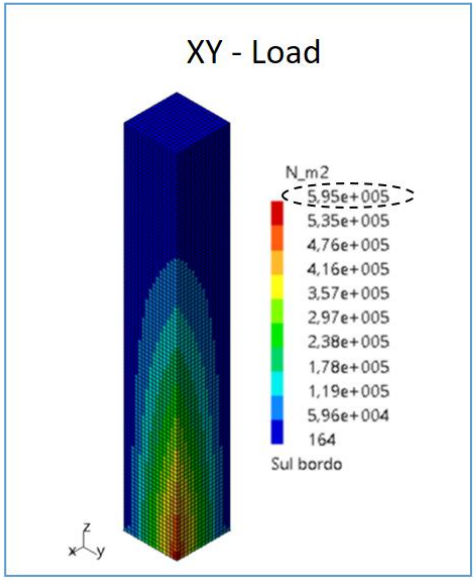
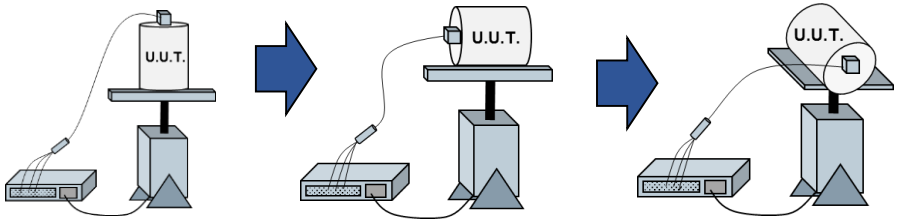
Max Stress for Single Axis Inputs



Max Stress for simultaneous Axis Inputs



Pay attention to mono axial -sequential testing. The damage location could be different from real life experience



Experimental analysis
Single vs Multi-axis excitation

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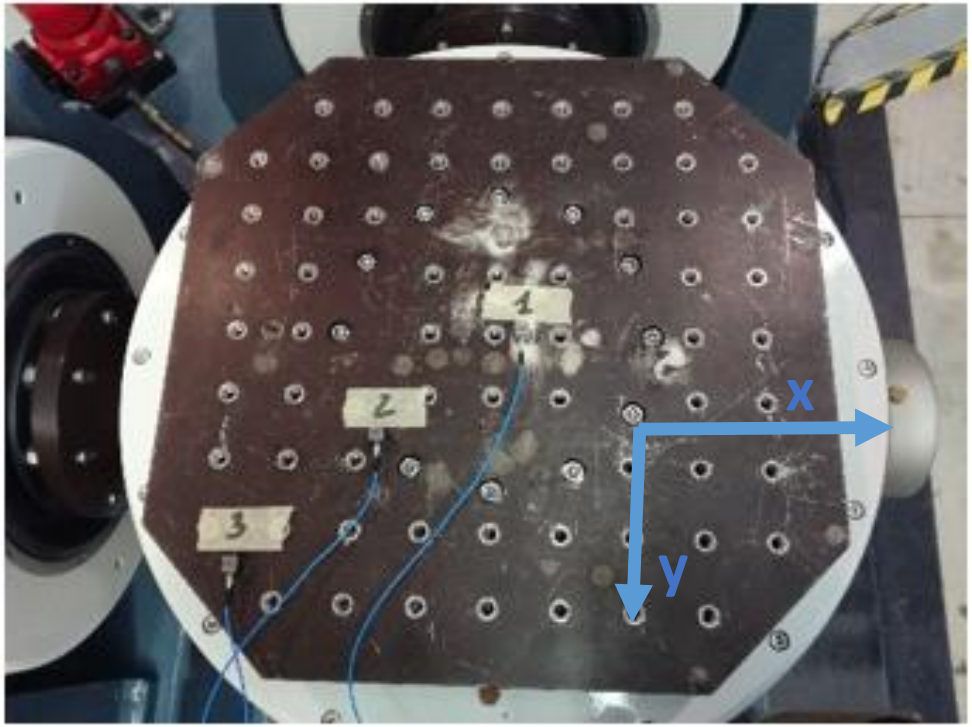
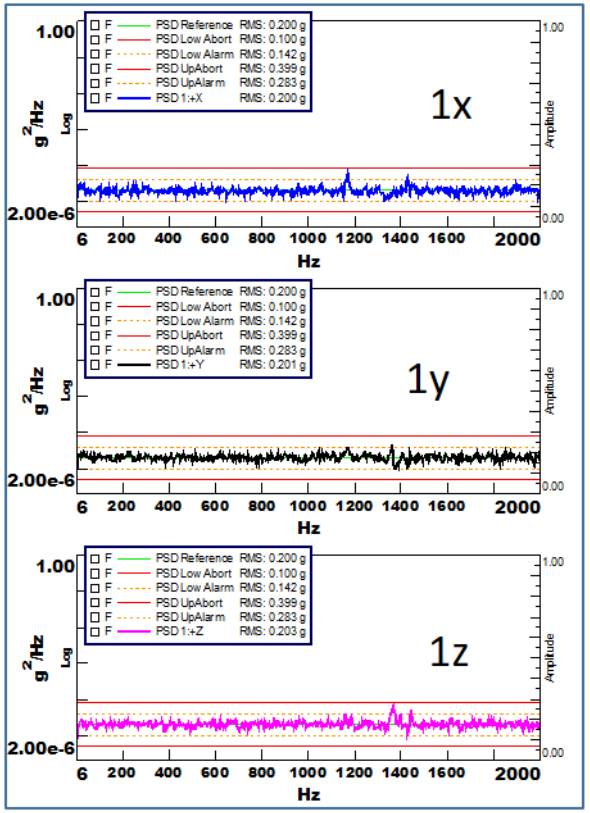


Control Point 1



The DongLing 3ES-10-HF and Siemens controller

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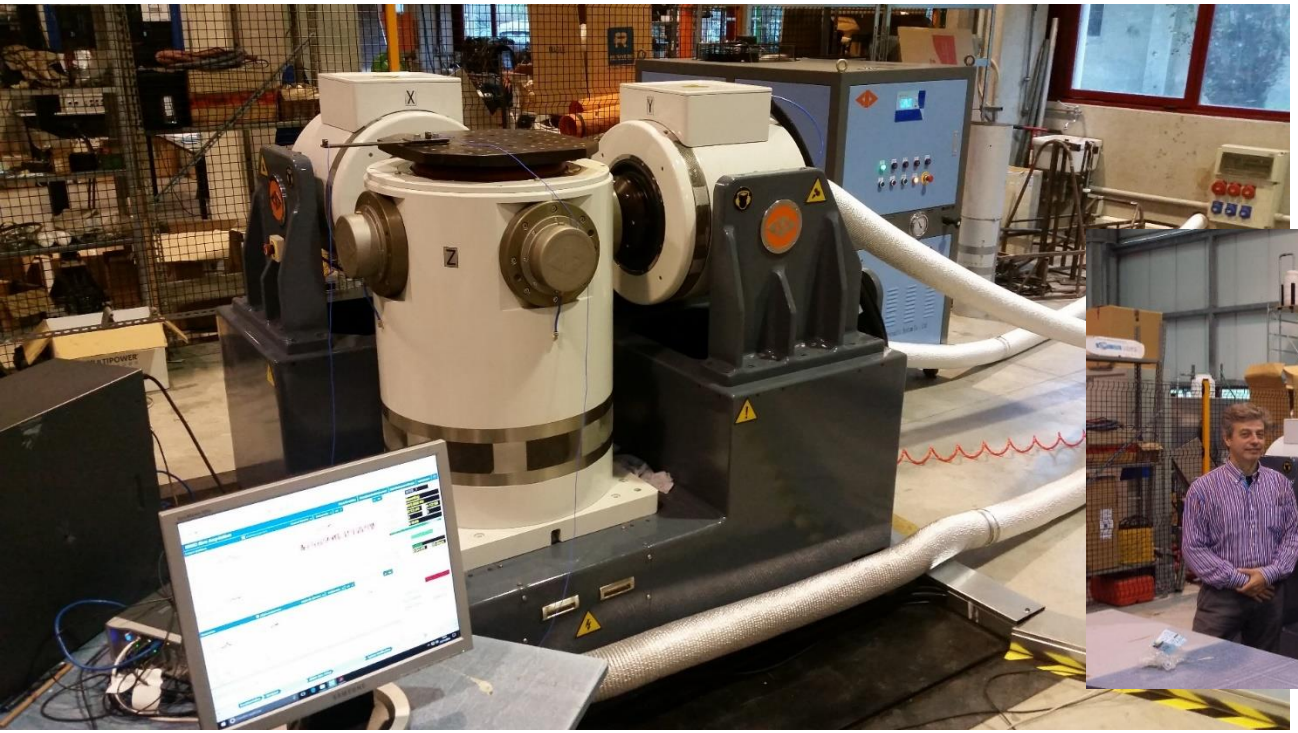
- Sine Force: 10kN; Random Force: 10kN; Max payload: 100kg; Table size: 500X500 mm; frequency range: DC to 2kHz; Vel MAX: 1.2m/s; Acc MAX: 6g/8g.
- Orthogonal Coupling Bearing Unit that uses high oil pressure and loading of hydrostatic bearing leading to not metal contact. Optimized throttle hole distribution to ensure the transmitting force.
- Siemens Controller: MIMO Random, MIMO Stepped Sine, MIMO swept Sine, MIMO Time Waveform Replicator for reproducing your own acceleration profile.



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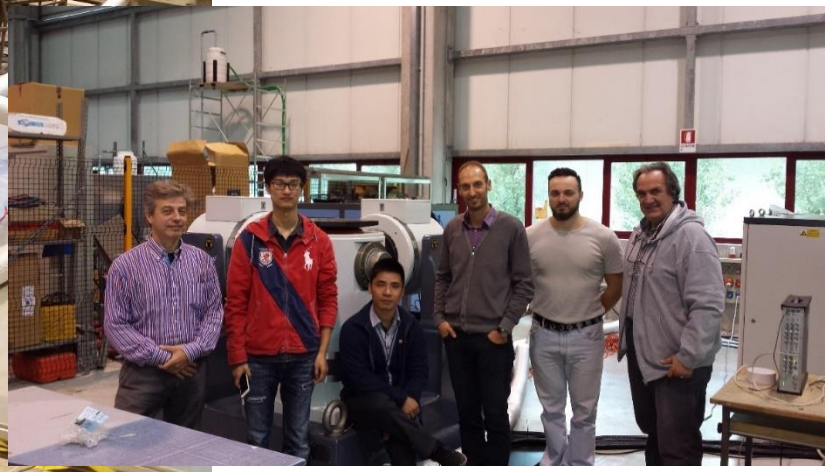

Set up - October 2016

Experimental analysis
Single vs Multi-axis excitation

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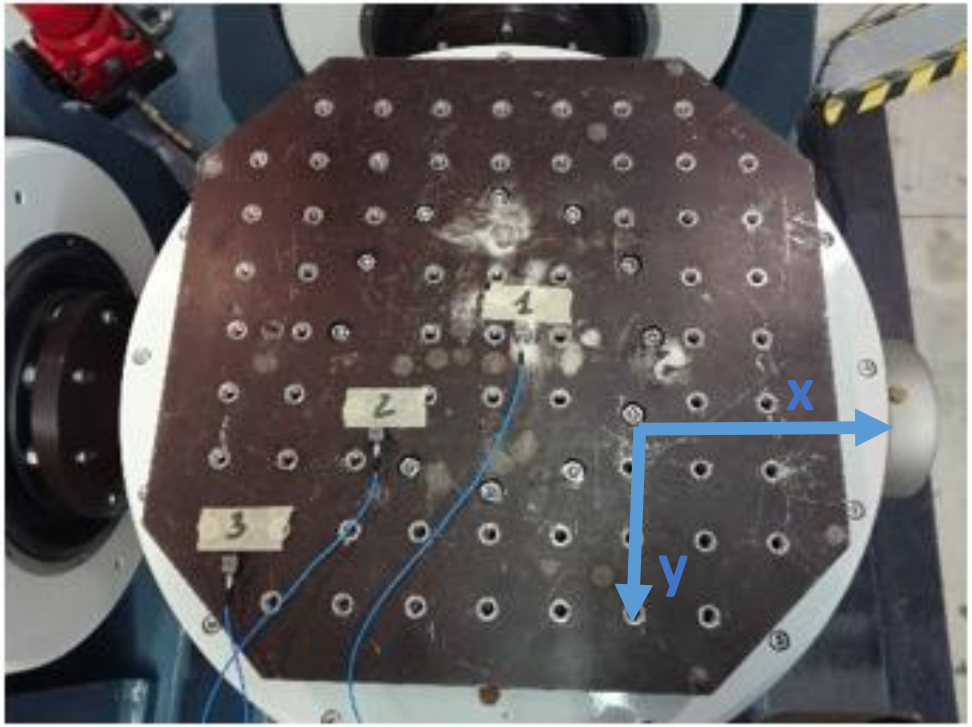
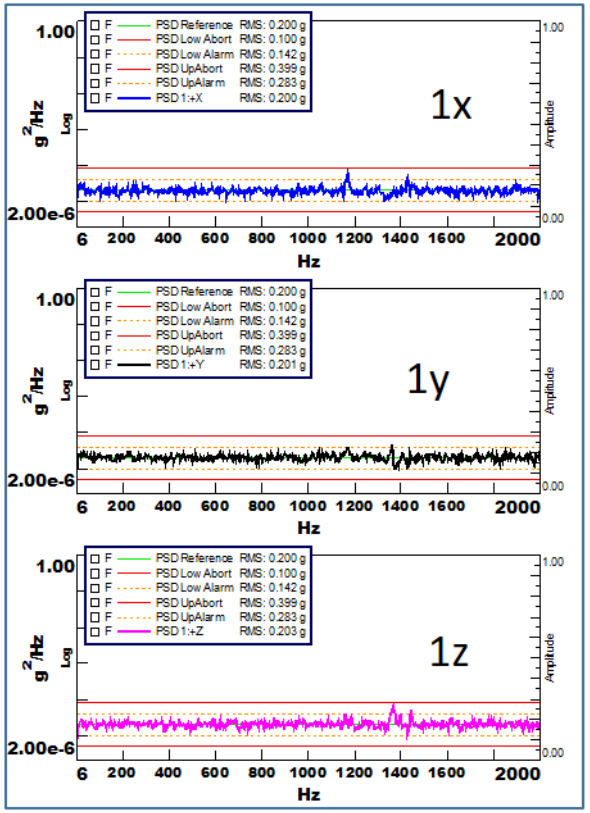


Control Point 1



Experimental analysis
Single vs Multi-axis excitation

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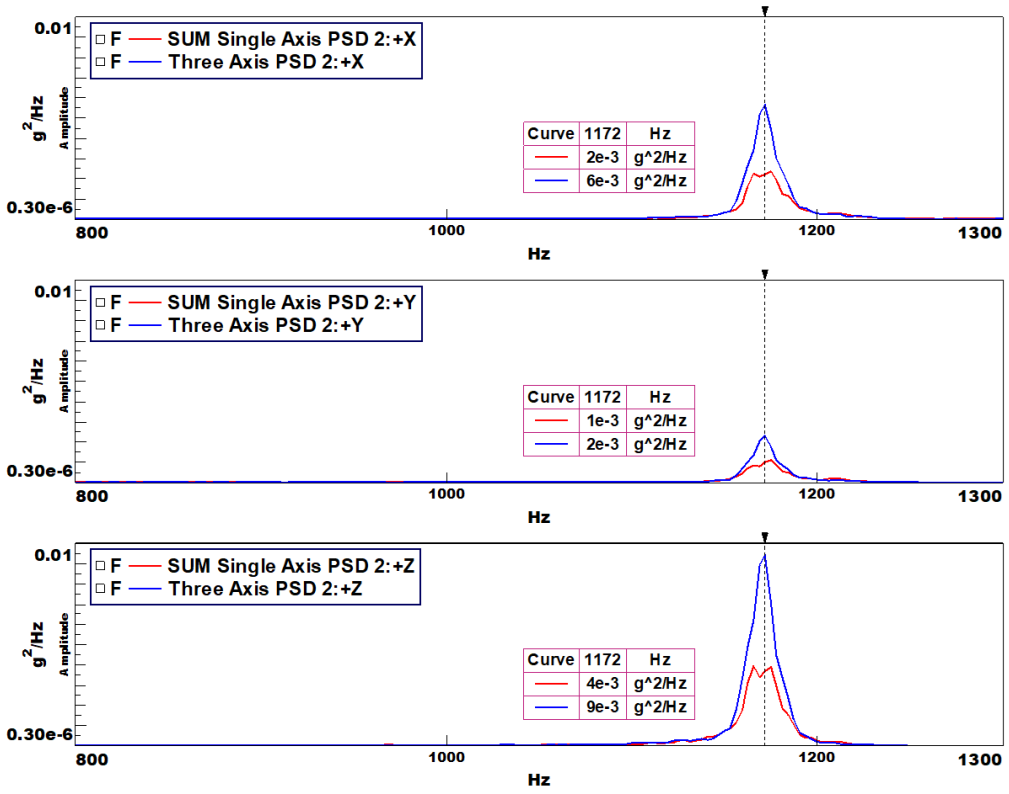

Measured Point 2

Sum [Mono-axial Excitation in X, Mono-axial Excitation in Y, Mono-axial Excitation in Z] → Triaxial Excitation → Response in X at point 2

Sum [Mono-axial Excitation in X, Mono-axial Excitation in Y, Mono-axial Excitation in Z] → Triaxial Excitation → Response in Y at point 2

Sum [Mono-axial Excitation in X, Mono-axial Excitation in Y, Mono-axial Excitation in Z] → Triaxial Excitation → Response in Z at point 2

Superposition of single axis excitations is very different from simultaneously tri-axial excitation

Outline

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Multi-axis testing
low vs high Coherence
(random control)

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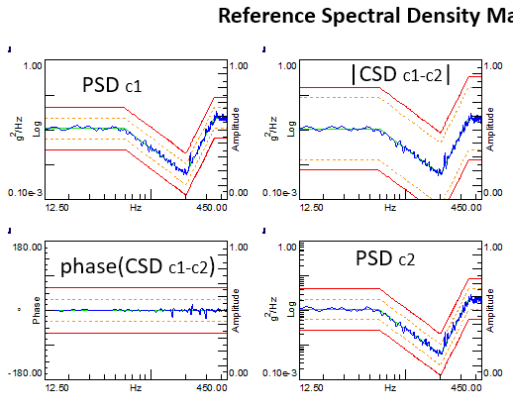

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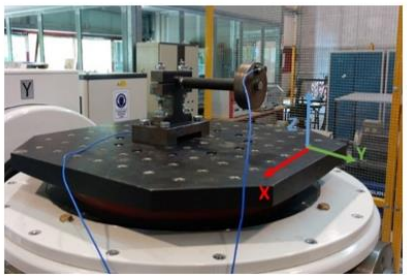
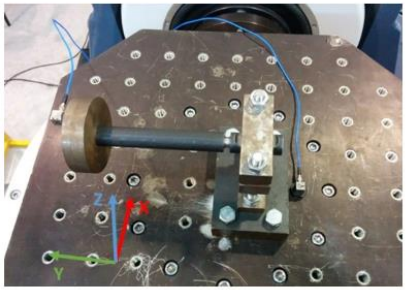
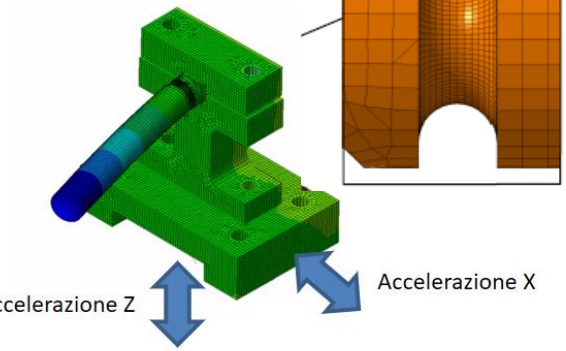
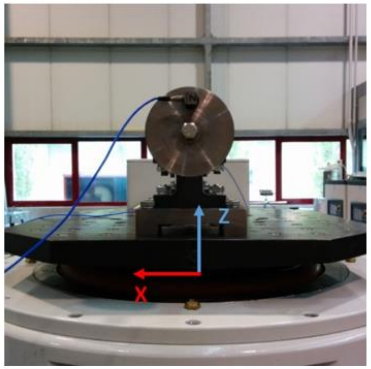
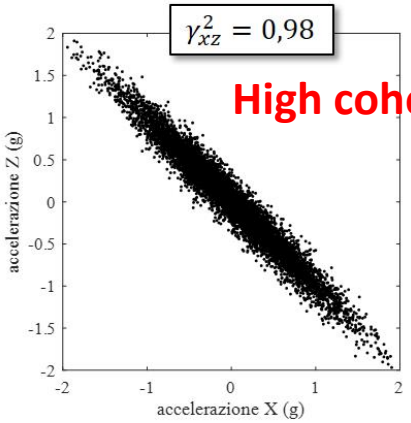


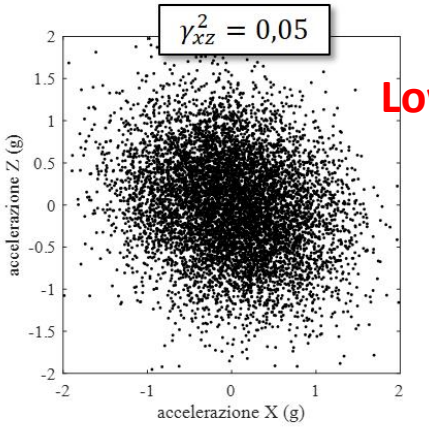








High coherence



Low Coherence

High coherence: the effect is to create vibration along the resultant axis (45deg) and the resultant magnitude $\sqrt{2}$ times

Low Coherence: real multi-axis test

Different Damages on specimen

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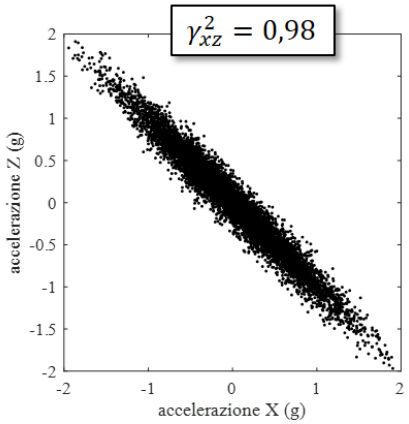
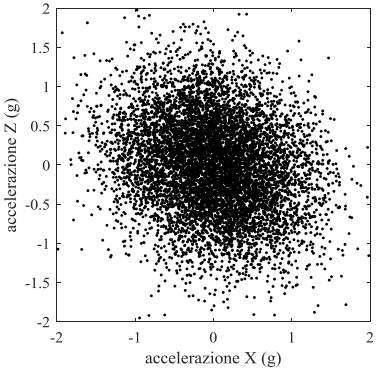
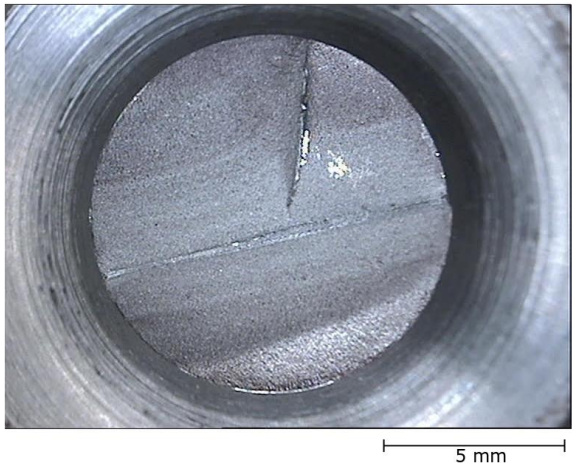


High Coherence: Similar to mono axial excitation



Low Coherence: Real multi axial excitation



Crack occurs along a precise direction

Reduction of the resistant section

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Accelerated vibration testing

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Dynamic tests:
Tests are necessary to assess the durability of mechanical components in their entire life

Problem: The requested durability for a mechanical component is usually of **thousands of hours.**

→ **It is necessary to reduce the duration of tests!**

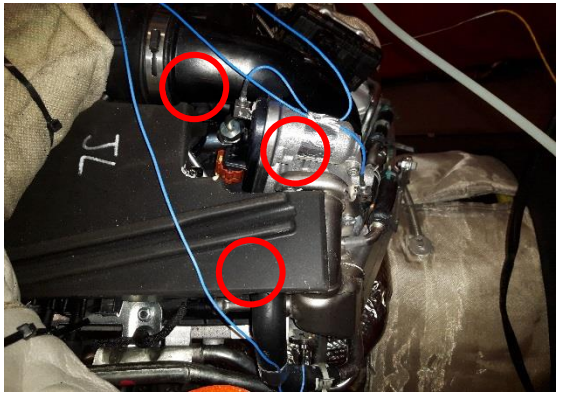
In order to reduce the testing time, some techniques have been developed to submit to mechanical components more demanding excitations if compared to the ones they normally undergo in operating conditions

The accelerated test must replicate the same damage observable on the component at the end of its life

C. Lalanne, *Mechanical Vibration & Shock Analysis*, Vol. 5, 2009, Wiley-ISTE

Accelerated vibration testing

Operational data
(mechanical component in its environment)



Calculation of the Extreme Response Spectrum (ERS) & Fatigue Damage Spectrum (FDS) for operational data

Synthesis of the PSD of the accelerated test

$$\frac{RMS_{operational\ data}}{RMS_{accelerated\ test}} = \left(\frac{T_{accelerated\ test}}{T_{operational\ data}}\right)^{b}$$

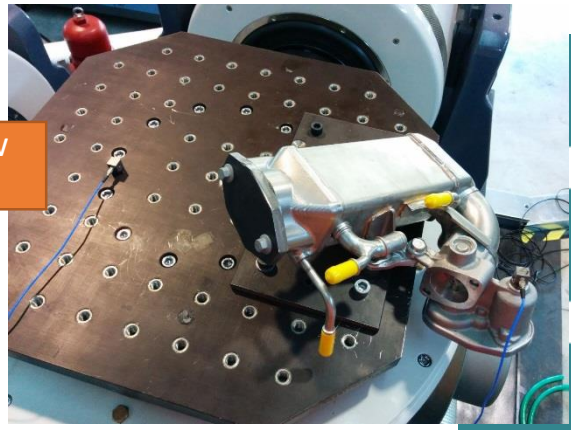
unknown

Calculation of ERS & FDS of the accelerating life excitation

Are the new ERS / FDS ok?

NO

Compute a new excitation PSD



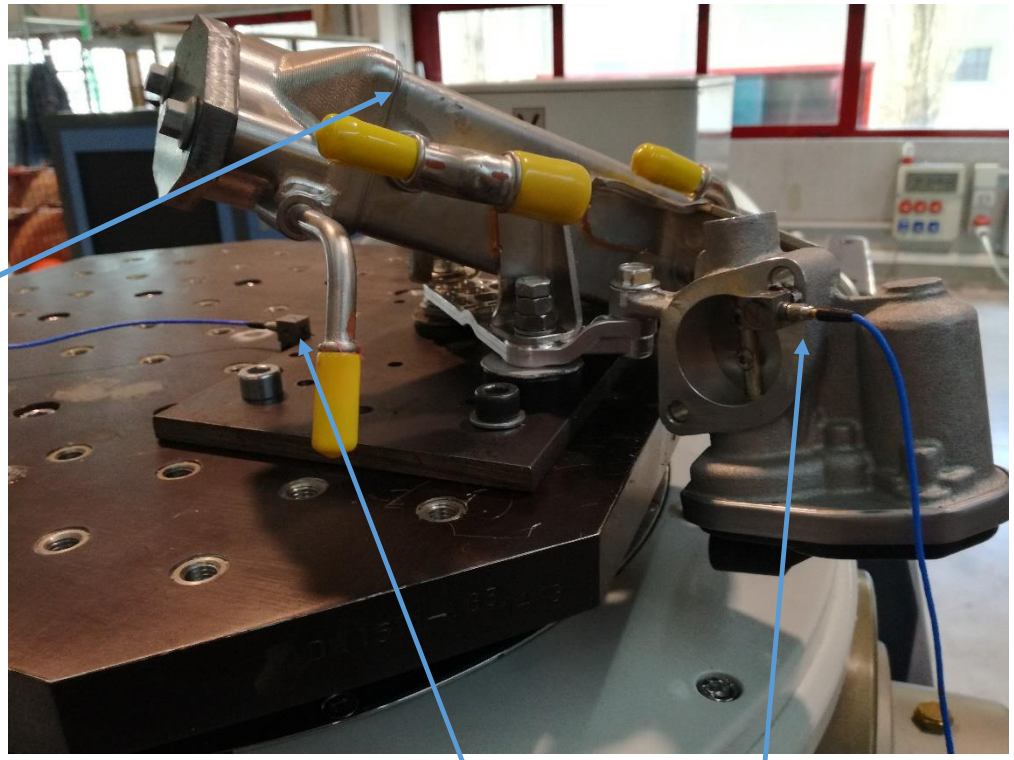
YES

Accelerated life testing

Case Studies . Fatigue life testing on EGR Valve of a Sport Italian Car

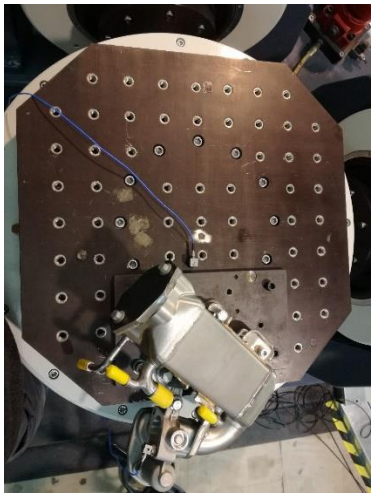
of

In operational conditions, the component shows a failure



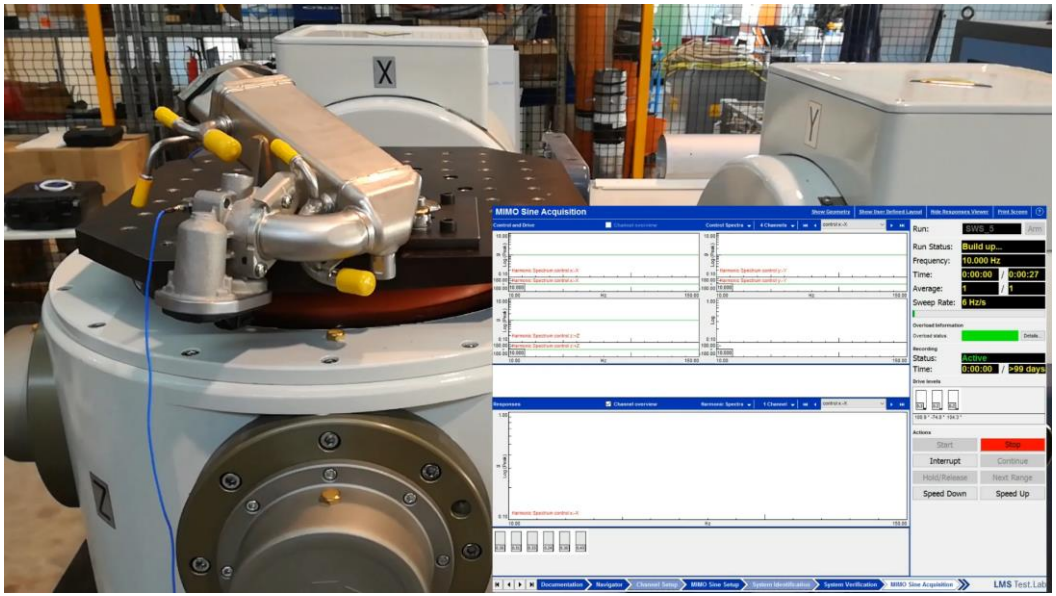
We perform an accelerated fatigue test with triaxial accelerations as input data

Same constrain as in the real engine



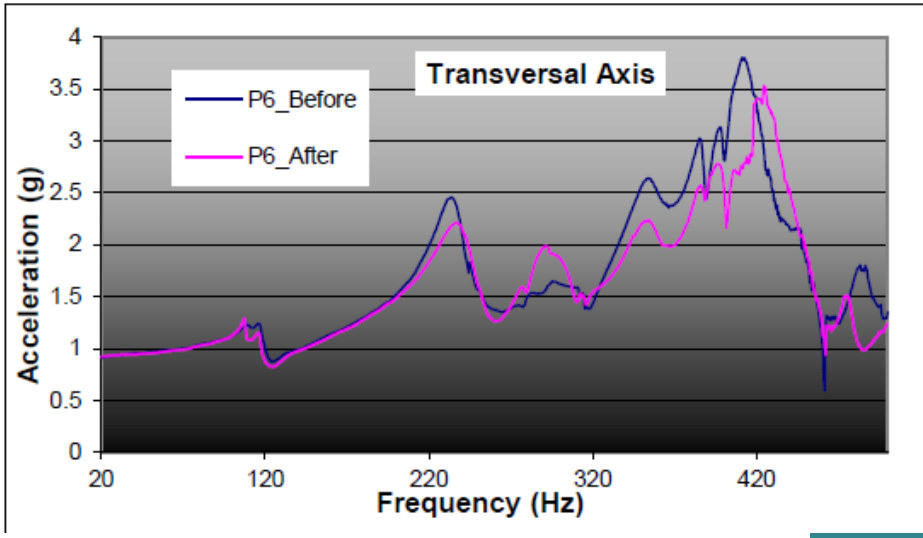
MIMO Sweep sine testing
MIMO Random testing

Sweep sine for resonance estimation (before and after accelerated life testing)



differences in terms of amplitude and frequency

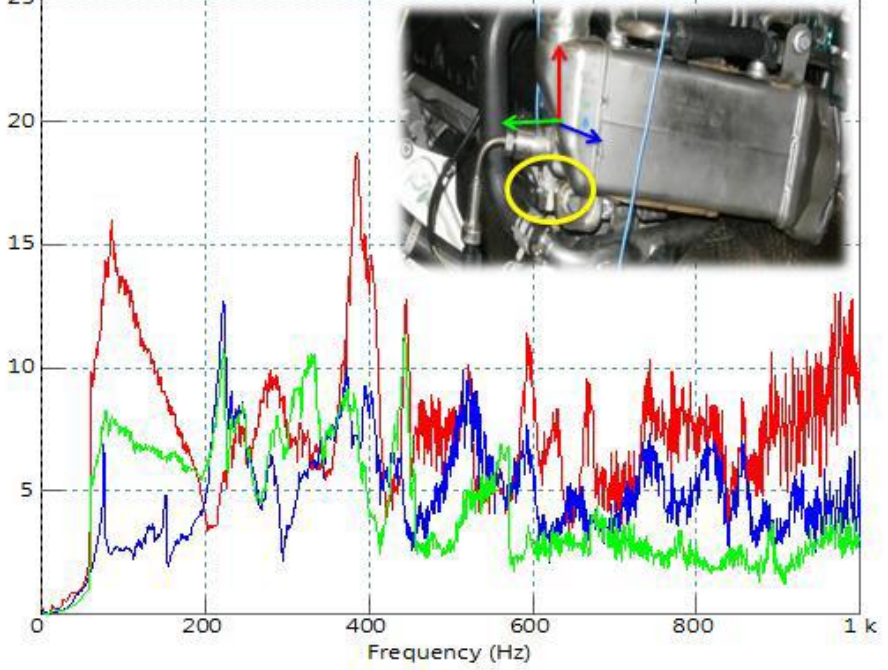
Sweep sine in the entire frequency range in order to estimate the natural frequencies

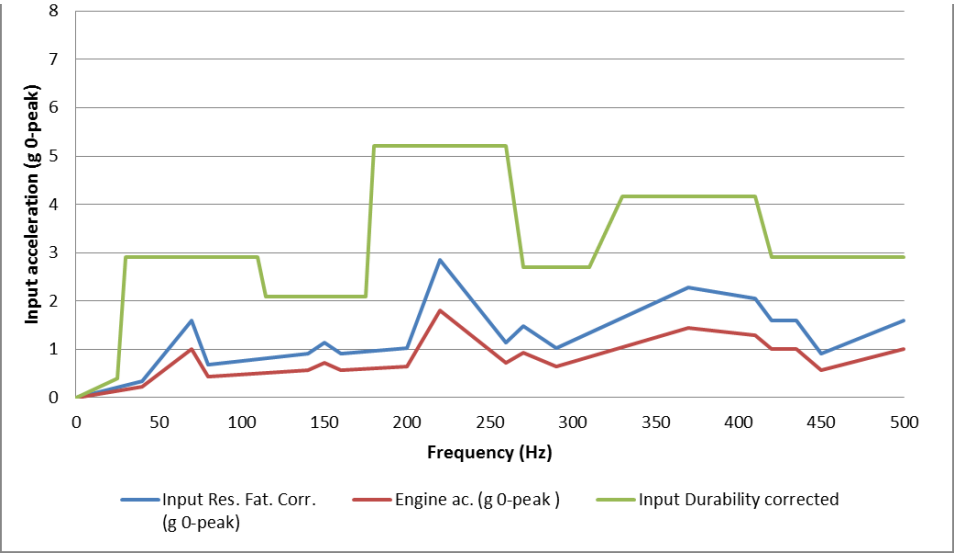


Multiaxial Random fat test

Acceleration profiles to be use in a random test:

1. **PSD during a Run up (operational data)**
2. **Accelerated PDS (based on FDS/ERS)**





Multiaxial Random fatigue test

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10 million cycles equivalence (3h on the 3D Shaker)

Evaluation of failure in the component

Case Studies - Experimental dynamic analysis of agricultural components subjected to multi-axial un-correlated excitation

Real life components are usually subjected to triaxial un-correlated (random) excitations cannot be brought back to mono-axial excitation

For the dynamic characterization of this component is necessary a vibration test system that enables a triaxial un-correlated (random) excitation

Very important is the quality of the controller that tunes real-time the excitation (non-linearities scenario)

Replication of time wave history obtained from real vibration test in operational condition (Time Wave Replicator)

Brake fluid-pipe of a driveline in an agricultural machine

Picture 12: Accelerometers on the left pipe

Time Waveform Replication

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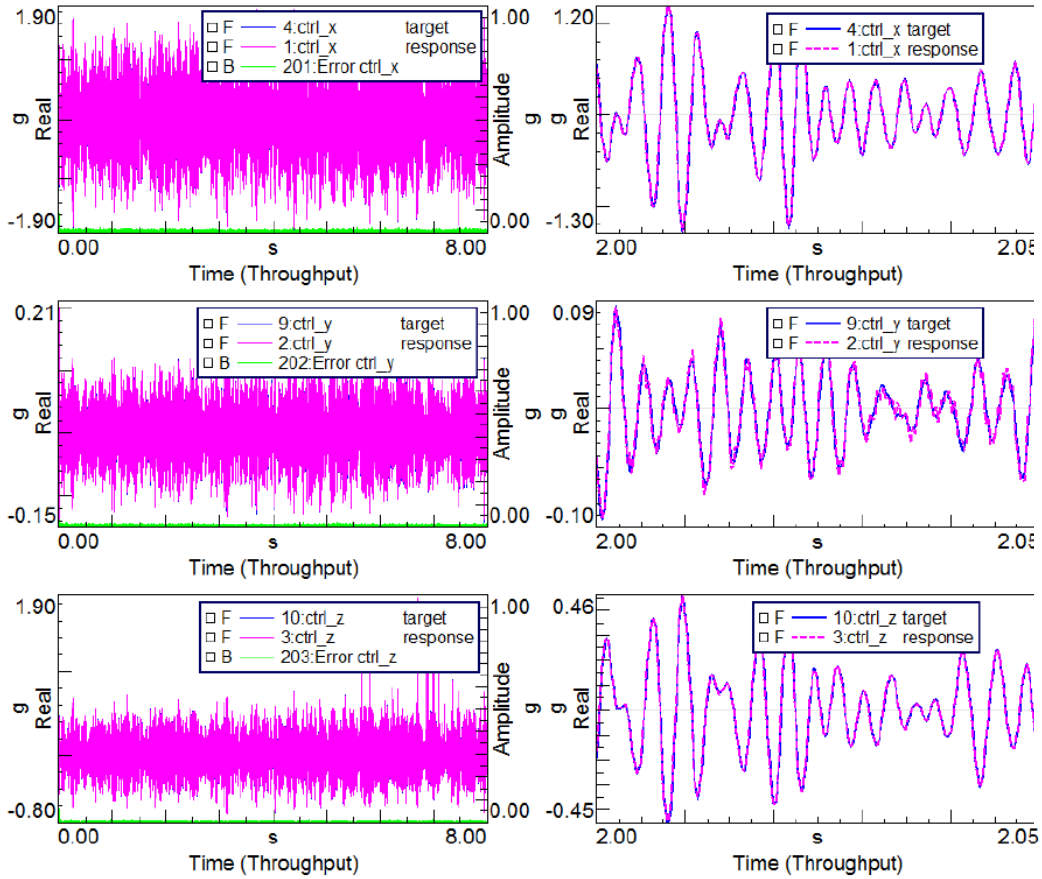
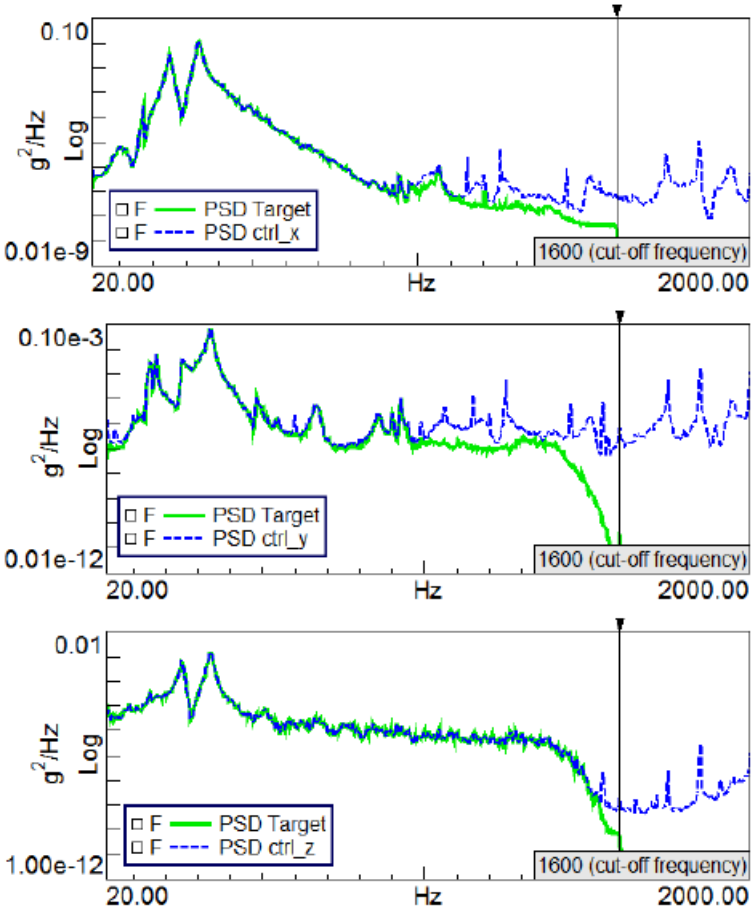
The Time Waveform Replication procedure enable to simultaneously replicate multiple time traces in a set of control points. The control process is an Iterative Learning Control that guarantees a fast convergence reducing the least error between the targets set and the recorded responses





USE THE TRIAXIAL SHAKER IN ORDER TO TEST DIFFERENT MODIFICATIONS , SINCE THE REAL TRANSMISSION WAS NOT AVAILABLE

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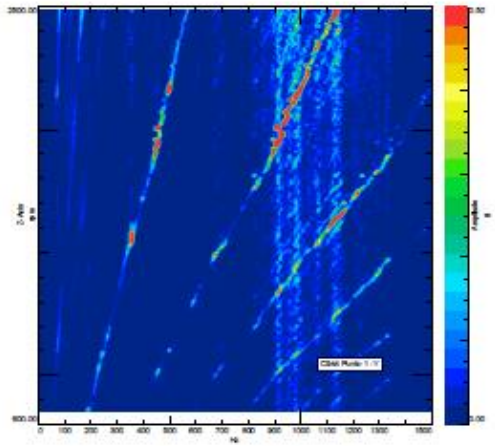
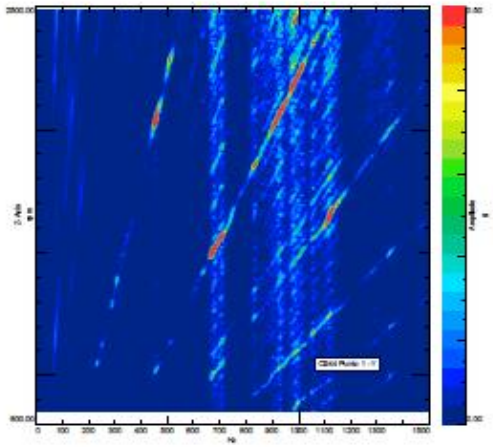
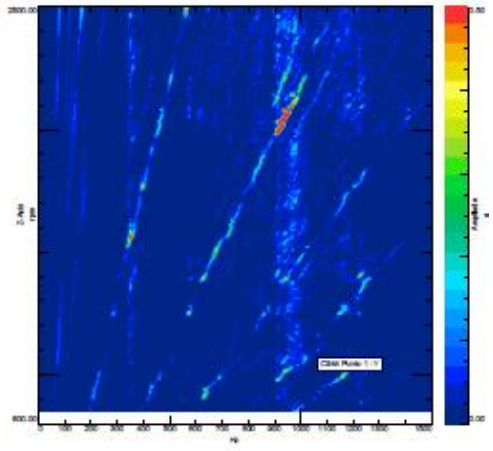
Baseline



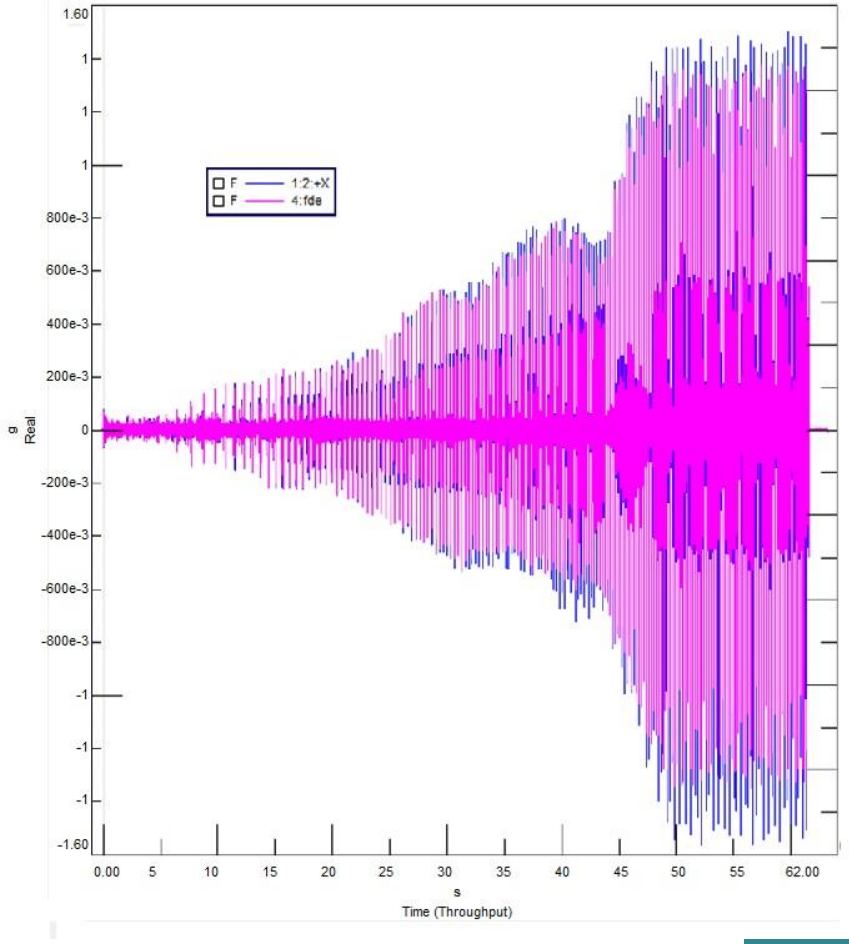
With bracket



With rubber grommet



Original signal and time wave replication



Conclusions

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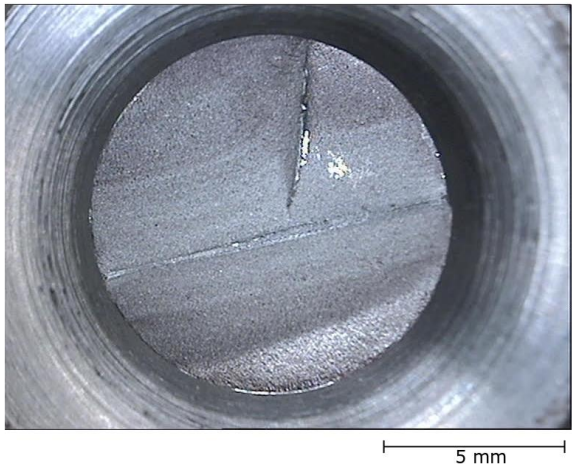
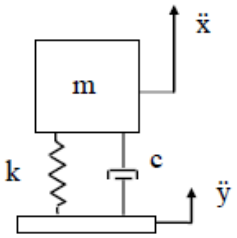
- Minimize the test time: three axes can reduce the testing time, shorter time than single axes.
- Reproduction reality environment: three axes shaker simulates reality dynamic environment more realistically than single shaker can do.
- Effect of the CSD (low vs high coherence)

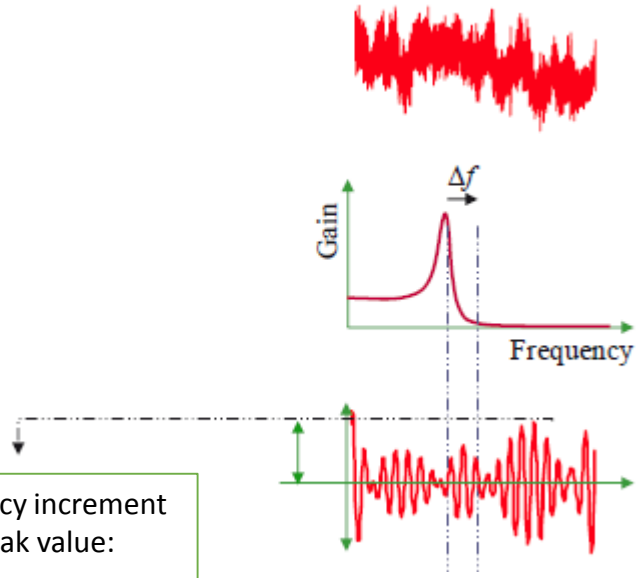


Case Studies 2. Test tailoring: definition of ERS & FDS



Foundation of the method:

- The component is representable as a SDOF system
- Its natural frequency can vary, spanning all the resonances of the component in the range of interest



Measured acceleration signal

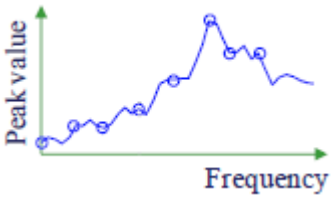
↓

The SDOF system acts as a filter with variable resonance frequency

↓

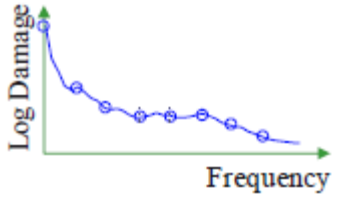
Filtered acceleration signal

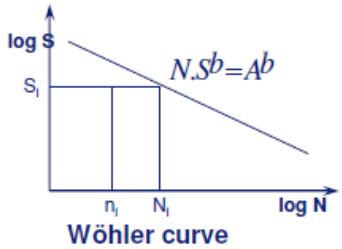
For each frequency increment Δf, extract the peak value:



ERS = plot of all the peak values as a function of the SDOF system natural frequency

Rainflow damage:





FDS = plot of the accumulated damage as a function of the SDOF system natural frequency

Università degli Studi di Ferrara

Department of Engineering Ferrara

Merci de votre attention

L'**université de Ferrara**, Italy,
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pour toutes **prestations d'études**
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Pour plus d'information,
merci de contacter

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