Purpose of environmental testing

- A lot of structures suffer from damage during normal operation OR during transport

- The purpose = often to predict/avoid this kind of damage
  = proof that a structure survives certain circumstances

- Ideas:
  - If structure functions well during a test, it should survive normal operation
  - If structure is damaged during a test, it will not survive normal operation …

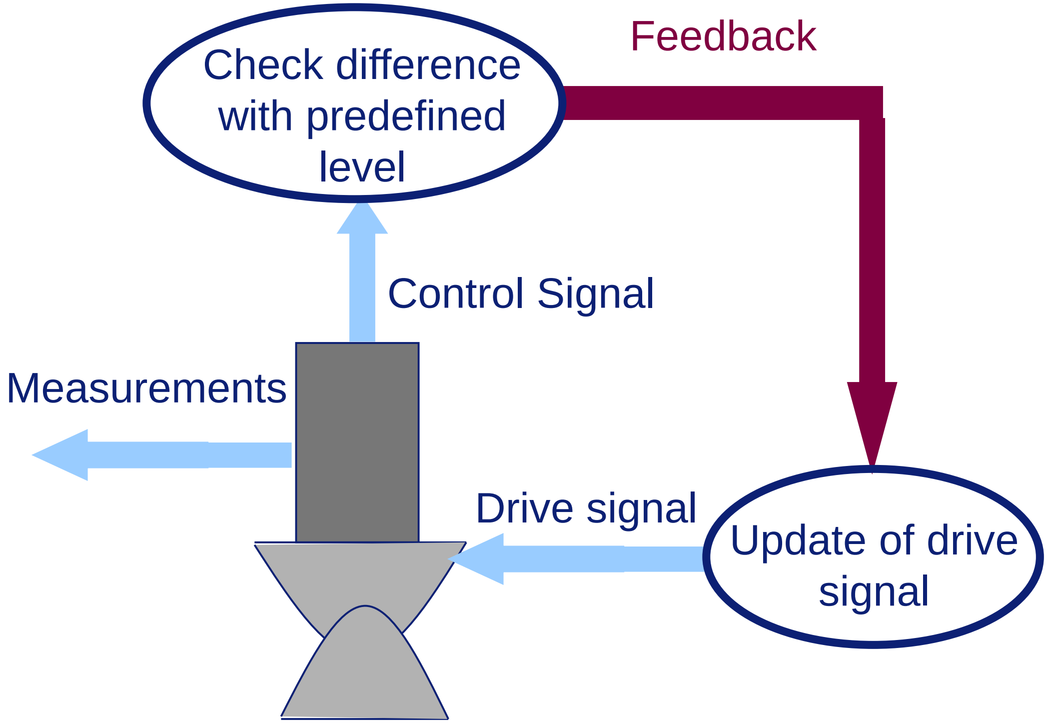
- So a good test will simulate conditions which are comparable to the operational conditions of the structure

⬇

Different types of environment tests are developed (see further)

Environmental testing in practice?

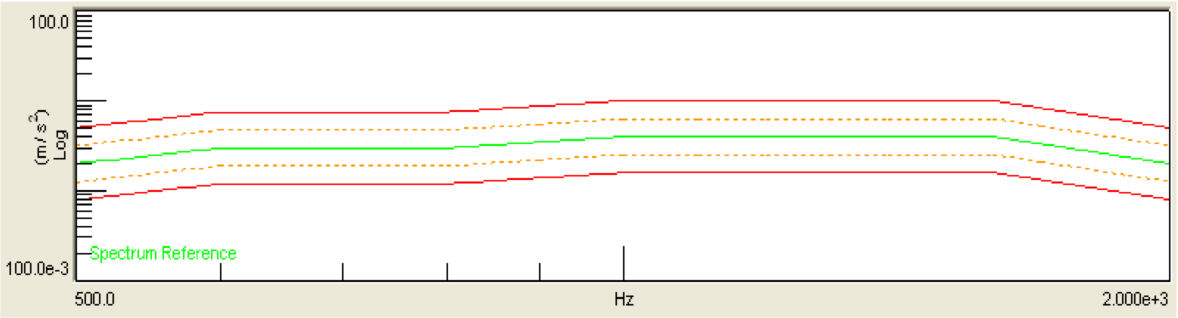
- Measuring the response of a structure when exciting the structure such that a control signal matches a predefined excitation level
- To do this, the drive signal needs to be constantly updated
- Control loop necessary



Purpose of the control loop

- To **shape the drive spectrum** such that the excitation of the control transducer matches a pre-defined level (reference spectrum)

For example:



- To verify that the test structure is **not in danger** and to shut down the test if it is

This is done through the checking of **abort** and **alarm** conditions

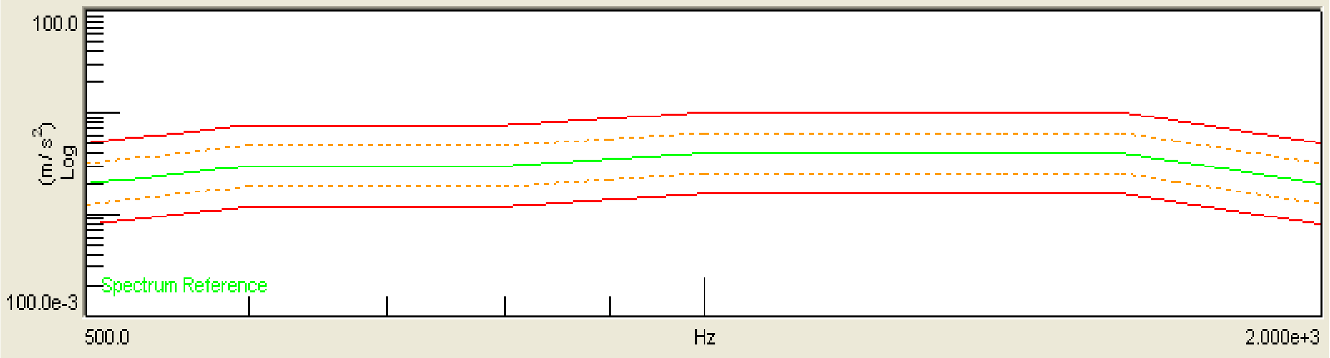
Types of environmental control

- Purpose is to simulate a signal which is comparable to the operation environment of the structure

- Groups of control signals:
    - Sine vibration control
    - Random control
    - Shock control
    - Combination
    - Time waveform replicator

Sine Control

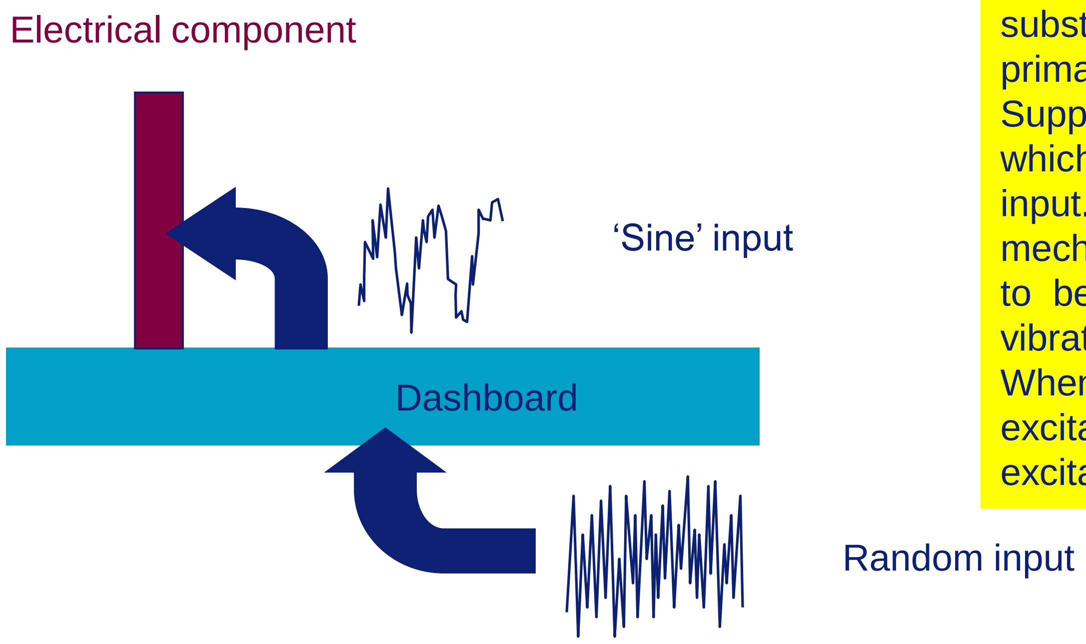
- Principle:
  - Excitation by a (sweeping) sine wave
  - Amplitude equals a reference profile (frequency spectrum)



Sine Control

- Advantages:
  - Control is very simple and straightforward
  - Very precise determination of eigenfrequencies possible
  - Ideal for substructures with dominant resonance mounted on basis structure

examples: - electrical components mounted on a dashboard
- parts of a satellite



If a large primary structure has a lot of substructures mounted on it, then the primary structure will be a mechanical filter. Suppose for example the dashboard of a car, which has a random road noise excitation as input. The dashboard will often be a mechanical filter, causing the substructures to be excited by a narrow-banded random vibration that resembles a sine vibration. When testing the substructure, a sine excitation will be a close to the operational excitation

Sine Control

- Disadvantages:
  - Reliable tests may take lot of time (low sweep rate, 1Hz per second)
  - Lot of energy at one frequency line may damage the structure (overtesting)
  - Excitation by sine wave might not be enough to determine the damage potential structures with complicated geometry and several eigenfrequencies

↓

Interaction between modes may cause damage

↓

The mode interaction will not be generated with sine excitation (since one frequency is excited at one time)

Summary:

Sine control = simple

simple structures with only one eigenfrequency within range of interest

If the test object has complicated geometry with several eigenfrequencies in the relevant frequency range interaction between the vibration modes, may cause damage. This damage will not be obtained by sine excitation. For these case multi axial random excitation will be necessary

Random Control

- Principle:
  - Excitation by a random signal
  - Frequency content of this signal equals a reference profile (power spectral density spectrum)

- Advantage:
  - More reliable test for more complex structures, with several eigenfrequencies

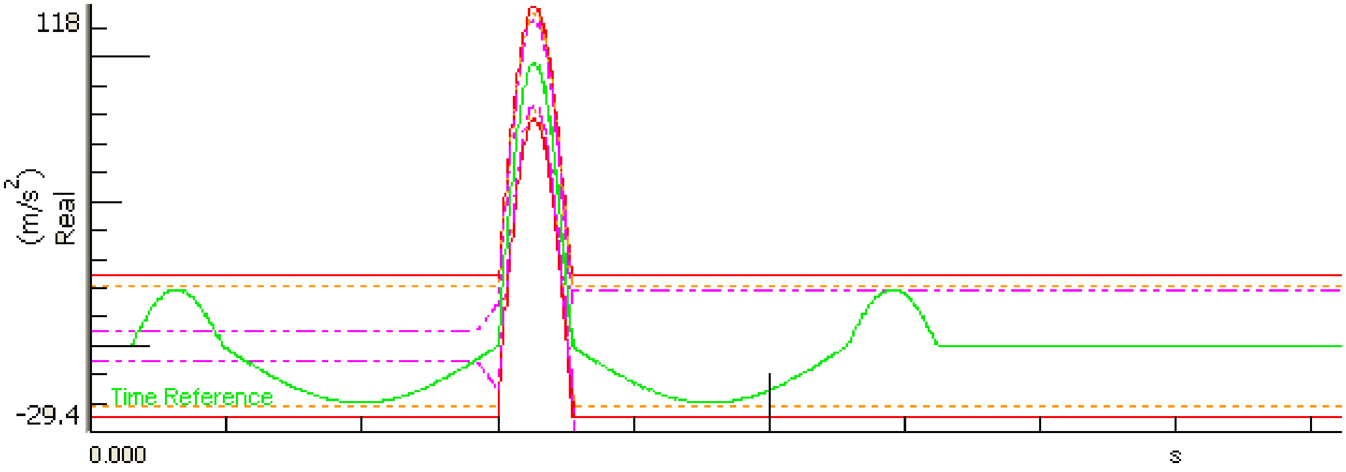
- Disadvantage:
  - Less precise determination of eigenfrequencies …
  - Not possible to bring enough energy in the structure over the whole frequency range

Random control :

More complex structures, which are excited by a random signal during normal operation

Shock Control

- Principle:
  - Excitation by a non-stationary shock
  - Shock impact equals a determined reference time signal



Applications of Shock Control

- Examples:

  - Transport: ability to survive a certain transport
  - Ability to withstand a certain impact
    (example: can a certain structure survive falling)
  - Military: damage potential of explosions
  - Safety: ability to withstand a certain nuclear explosion

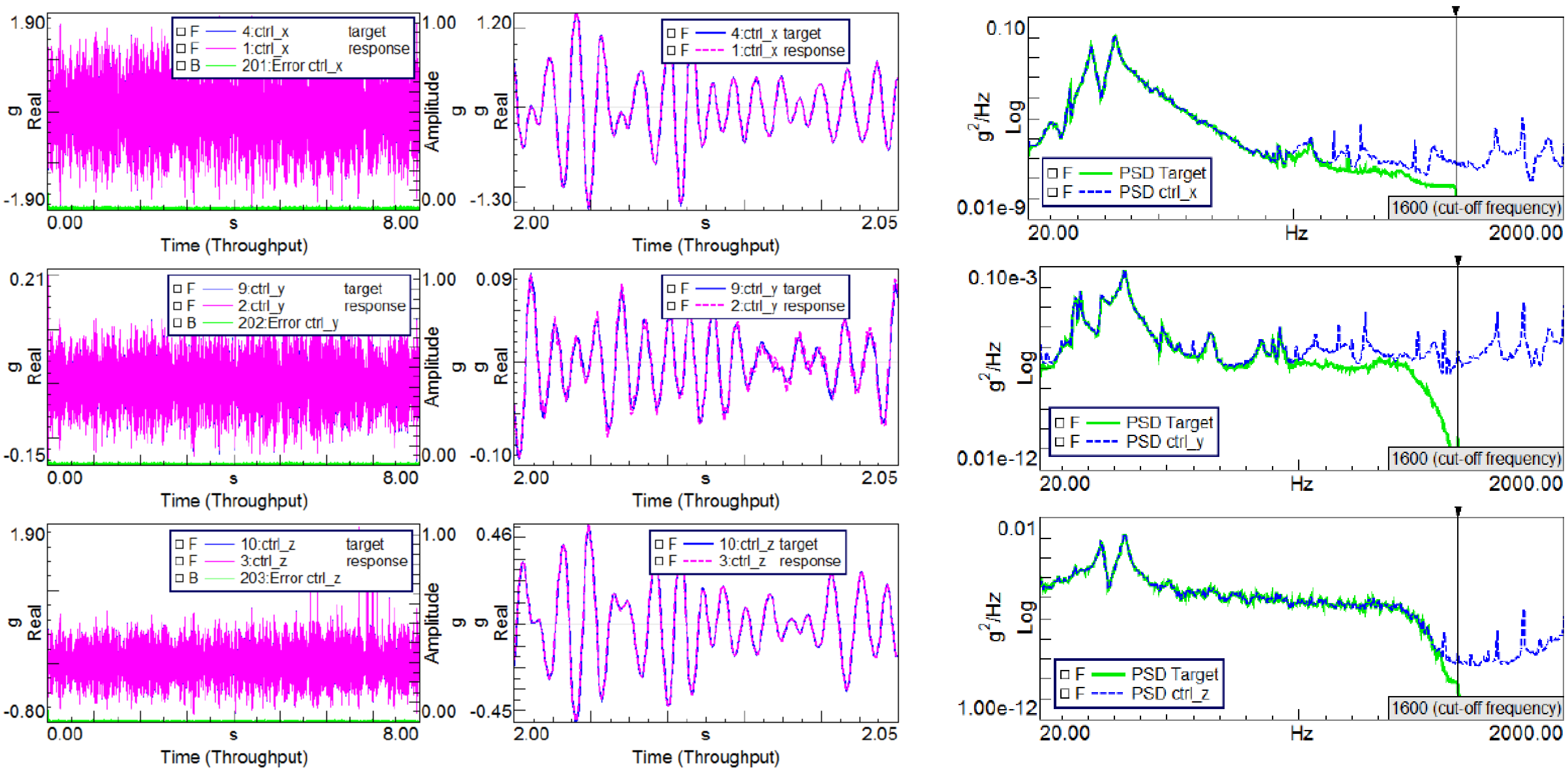
Combined Mode Testing

- Principle:
  - Actual vibration environment consists of:
    - background random excitation
    - stationary random and periodic components
  - Sine components and Random Components controlled **separately** (Sine on Random)

- Typical examples:
  - propeller aircraft
  - military jet aircraft (with or without on-board gunfire),
  - helicopters
  - tracked vehicles
  - automobiles during acceleration or ABS braking

Time Waveform Replication

The Time Waveform Replication procedure is the current state-of-the-art solution to simultaneously replicate multiple time traces in a set of control points. The control process is a proprietary frequency-domain Iterative Learning Control that guarantees a fast convergence reducing the least error between the targets set and the recorded responses



Accelerated vibration testing

Test dinamici:
Necessità di testare la durata di un componente meccanico per tutto l'arco della sua vita.

Problema: la durata richiesta di un componente meccanico è dell'ordine di migliaia di ore.

→ **È necessario accorciare la durata del test!**

Per accorciare il dispendio di tempo si sono messe a punto tecniche per sottoporre i componenti meccanici a sollecitazioni dinamiche più gravose rispetto quelle a cui sono sottoposti in normali condizioni di funzionamento

Attenzione: le sollecitazioni che agiscono sul componente sono di natura stocastica → le modalità di danneggiamento sono interessate dalla fatica multiassiale random.

Il test accelerato deve replicare la stessa modalità di danneggiamento rilevabile sul componente a fine vita

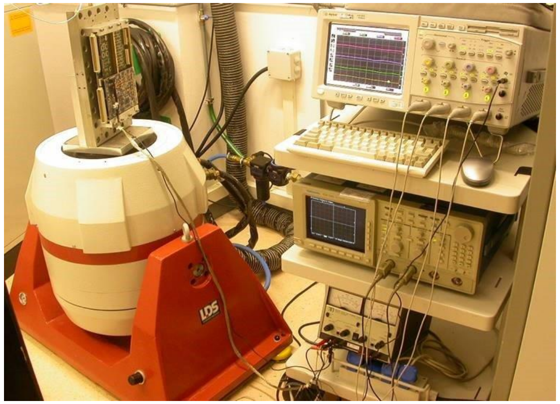
C. Lalanne, *Mechanical Vibration & Shock*, Vol. 5, 2009, Hermes Penton Ltd., London

Accelerated vibration testing

Normative di riferimento:
Tutte le normative di riferimento attuali sono derivate da applicazioni militari

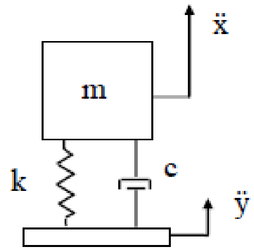
- NATO
- RTCA DO160
- MIL-STD 810:
  introducono il concetto di **test tailoring = il test accelerato deve essere tarato sulle reali sollecitazioni che il componente meccanico subisce durante l'esercizio**

Applicazioni:
- Industria aerospaziale: avionica, componenti della fusoliera
- Automotive: tubazioni common rail, componenti sottoposti a forti sollecitazioni in generale
- Industria elettronica: schede elettroniche sottoposte a forti vibrazioni



In tutti i casi i test sperimentali vengono condotto con shaker (oleodinamici o, sempre più spesso, elettrodinamici, visto il più ampio intervallo di frequenze utilizzabile)

Accelerated vibration testing



Componente schematizzato come **sistema SDOF con eccitazione della base**

Eccitazione della base:

- Swept sine
- Random (gaussiano / non gaussiano)

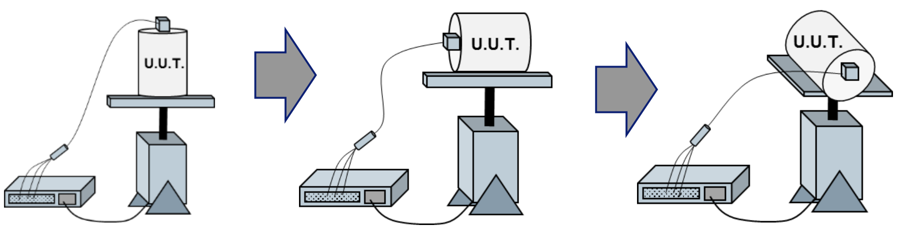
↓

In ogni caso l'eccitazione è **monoassiale** (vista la quasi totalità degli shaker sul mercato)

Per componenti meccanici complessi le normative suggeriscono di **ripetere il test in 3 posizioni** dell'oggetto in accordo alle direzioni degli assi cartesiani

Esempio (secondo MIL-STD 810 G):

- Swept sine iniziale per trovare le frequenze naturali del componente
- Random gaussiano. La normativa impone:
  - Profilo della PSD dell'eccitazione (da scegliere in base all'impiego del componente)
  - Durata del test
- Eventuale ripetizione del test nelle altre 2 direzioni cartesiane
- Swept sine per valutare se sono cambiate le frequenze naturali del componente



Accelerated vibration testing

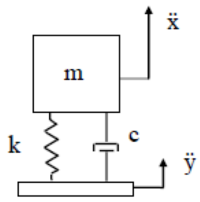
Extreme Responce Spectrum (ERS) e Fadigue Damage Spectrum (FDS): parametri utili a quantificare la gravosità dell'ambiente in cui opera il componente meccanico oggetto di studio in termini di deformazioni massime e danneggiamento a fatica

La MIL-STD 810 prevede l'utilizzo di 2 parametri:

- Extreme Response Spectrum (ERS)
- Fatigue Damage Spectrum (FDS)

Ipotesi alla base del metodo:

- Componente schematizzabile come sistema a 1gdl

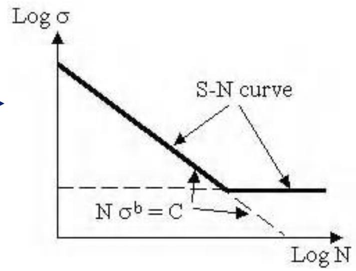


Ipotesi fortemente semplificativa, tuttavia permette di utilizzare il metodo già nelle fasi preliminari di progettazione, quando il componente in oggetto non ha ancora una geometria definita e un modello FEM non è disponibile!

- Tensione proporzionale allo spostamento della massa concentrata

$$\sigma \propto (x - y)$$

- Curva di Wohler approssimabile con la legge di Basquin

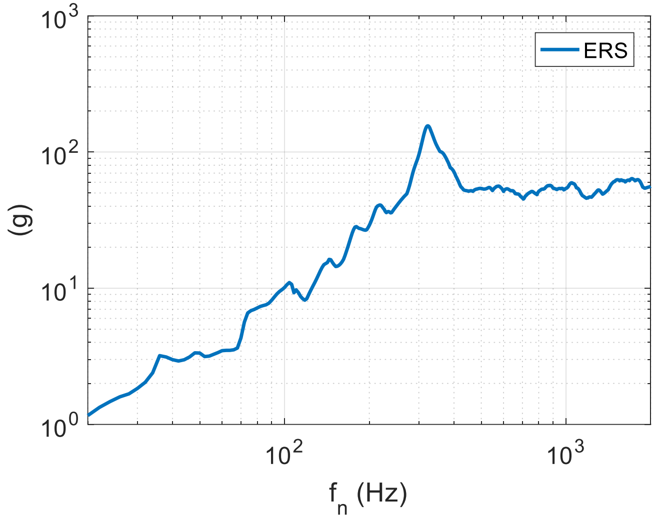


- L'accumulo del danno segue la legge di Miner

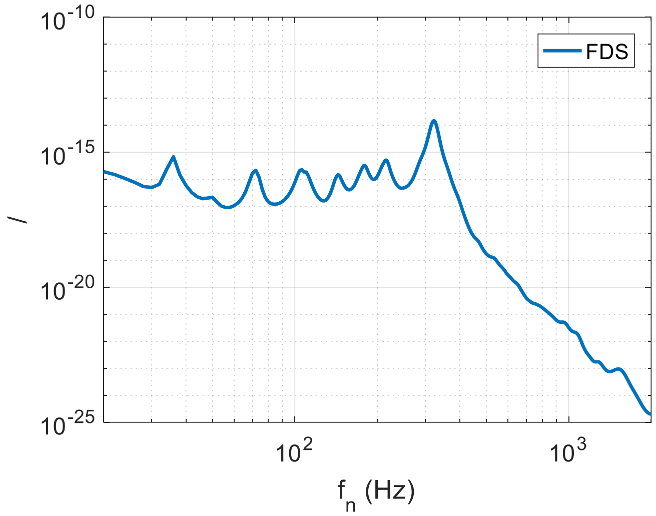
$$D = \sum_i \frac{n_i}{N_i} = \int_0^{t_f} \frac{dn}{N}$$

Accelerated vibration testing

Extreme Response Spectrum



Fatigue Damage Spectrum



ERS = accelerazione massima del sistema SDOF in funzione della possibile frequenza naturale

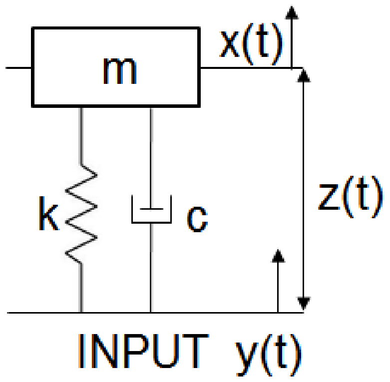
(utile per valutare la deformazione massima del sistema)

FDS = grafico del danno accumulato secondo Miner dal sistema SDOF in funzione della possibile frequenza naturale

(utile per stimare il danneggiamento a fatica subito dal sistema)

La frequenza naturale del sistema SDOF viene variata in un range di frequenze tali da coprire le frequenze di risonanza del componente in esame

Accelerated vibration testing

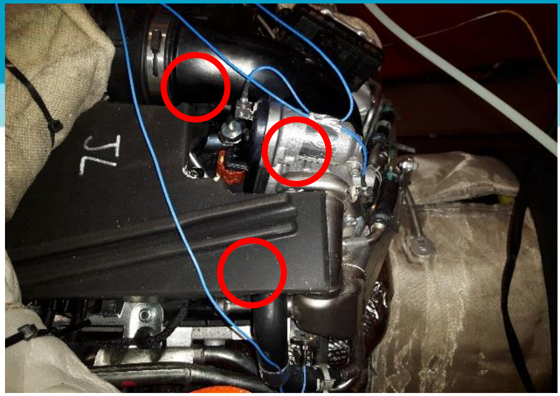


$$\textbf{ERS} = (2\pi f_0)^2 z_{rms}\sqrt{2\ln\left(\frac{1}{2\pi}\frac{\dot{z}_{rms}}{z_{rms}}T\right)}$$

$$FDS = \frac{K^b}{C}\left(\frac{1}{2\pi}\frac{\dot{z}_{rms}}{z_{rms}}\right)T\left(\sqrt{2}z_{rms}\right)^b\Gamma\left(1+\frac{b}{2}\right)$$

Accelerated vibration testing

Operational data
(mechanical component in its environment)



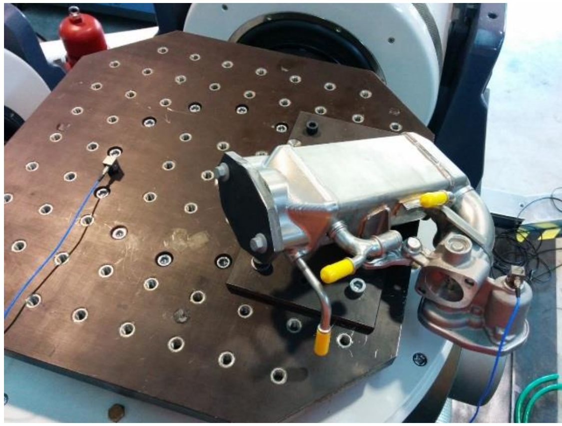
Calculation of the Extreme Response Spectrum (ERS) & Fatigue Damage Spectrum (FDS) for operational data

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

Esercizio – tavola vibrante

- Sine control
  - Sine control of an exhaust system of cars (verify control channels and measurement channels)
- Random control
  - Random control of an exhaust system of cars (verify control channels and measurement channels)
- Time Waveform Replicator
  - TWR of an exhaust system of cars (verify control channels and measurement channels)