InnoTesting 2024 - Wildau

The 3P‘s of Fatigue Damage Spectrum – Promises, Problems, Prospects

01.03.2024

Tiasa Ghosh[1], Prof. Dr.-Ing. Thomas Kuttner[1], Prof. Dr.-Ing. Elmar Woschke[2]

[1]Universität der Bundeswehr München, [2]Otto-von-Guericke Universität Magdeburg

Agenda

- Introduction and motivation: Test acceleration and Fatigue Damage Spectrum (FDS)
  - Process of FDS
  - Parameters and assumptions of FDS
- Parameter 1: Relationship between stress and vibrational parameters
- Parameter 2: Slope of S-N curve of a material
- Comparison of FDS with different parameters
- Summary
- Outlook and prospects

Introduction

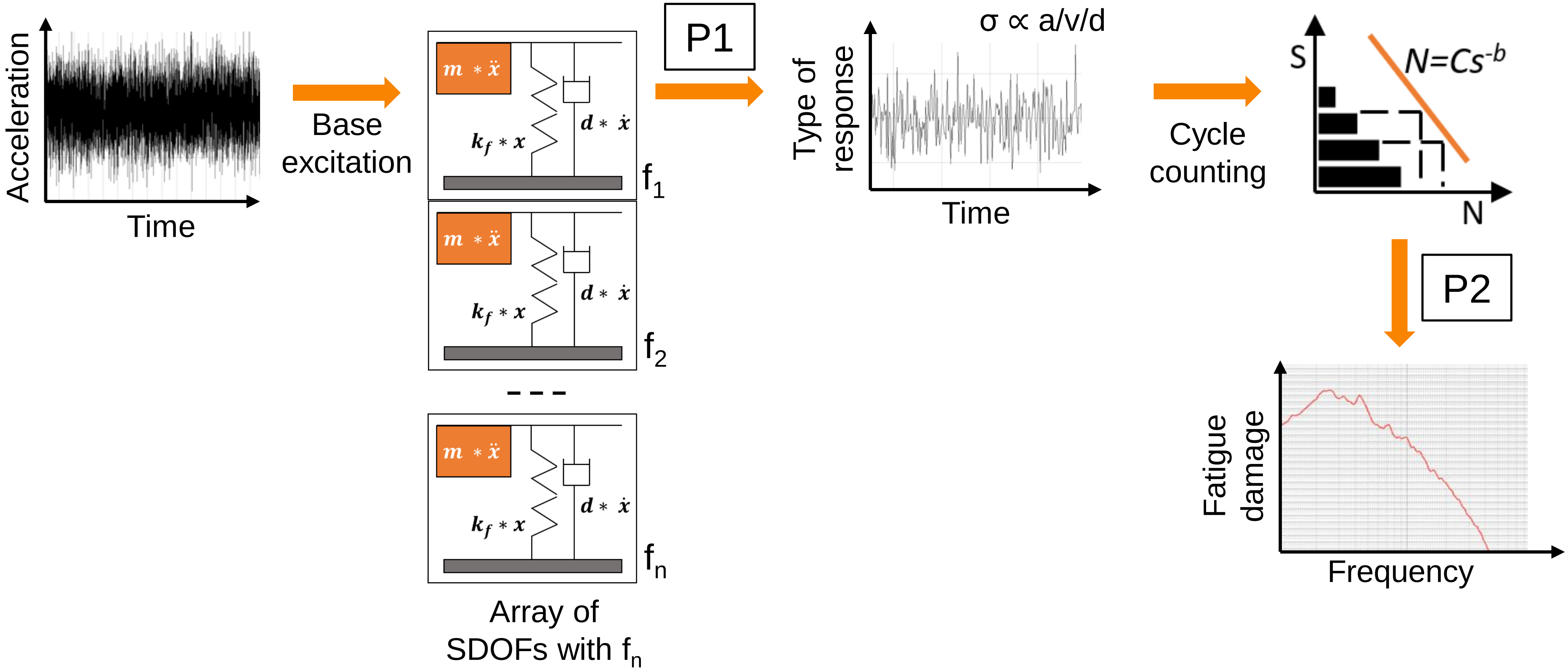
- Motivation:
  - Accelerated vibration testing
    - Simulate operational vibrations with shortened test time
    - Time and cost efficient

- Issues:
  - Simple scaling up of test amplitudes might be dangerous!
    - Exceedance of ultimate stress limits
    - Alteration of failure mechanism
    - Non-linear behaviour in components

- Promises:
  - Test acceleration with Fatigue Damage Spectrum (FDS)
    - FDS is a plot of cumulative fatigue damage experienced by an array of linear single degree-of-freedom systems with varying natural frequencies.
    - Reduce test time $\longrightarrow$ equivalent fatigue damage at each frequency band

Introduction to Fatigue Damage Spectrum

Process and parameters of FDS

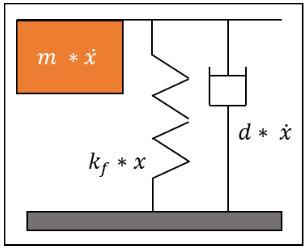


- Important input parameters (and problems!)
  - P1: Type of system response (relationship between stress and a vibrational parameter i.e. displacement, velocity or acceleration) along with quality factor Q
  - P2: Slope of S-N curve of the material

Parameter 1: Relationship between stress and a vibrational parameter

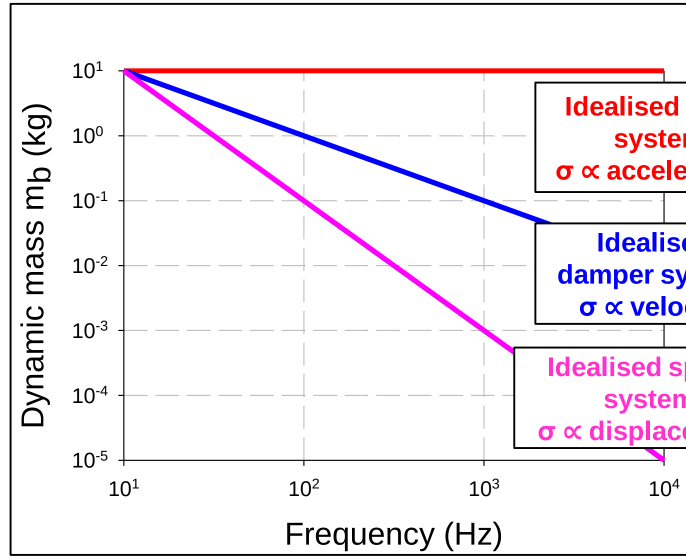
SDOF and dynamic mass

- Dynamic mass $m_b = \frac{\text{Mechanical impedance}}{\text{Angular frequency}}$



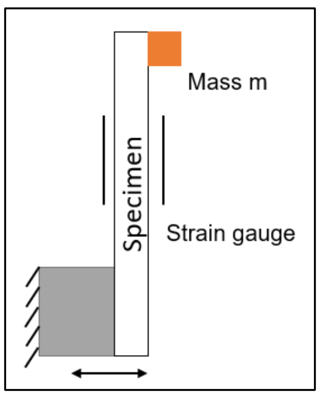
General SDOF

m_b	Idealised system
$\frac{Z_m}{\omega}$	Mass: $\frac{\sigma_{bmax}}{a}$
$\frac{Z_d}{\omega}$	Damper: $\frac{\sigma_{bmax}}{a\ \omega}$
$\frac{Z_f}{\omega}$	Spring: $\frac{\sigma_{bmax}}{a\ \omega^2}$

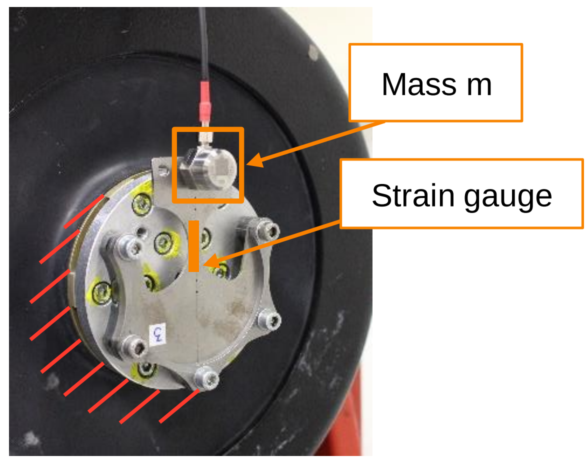


Dynamic mass of idealised components

Experimental setup with electrodynamic shaker



Bending beam with point load

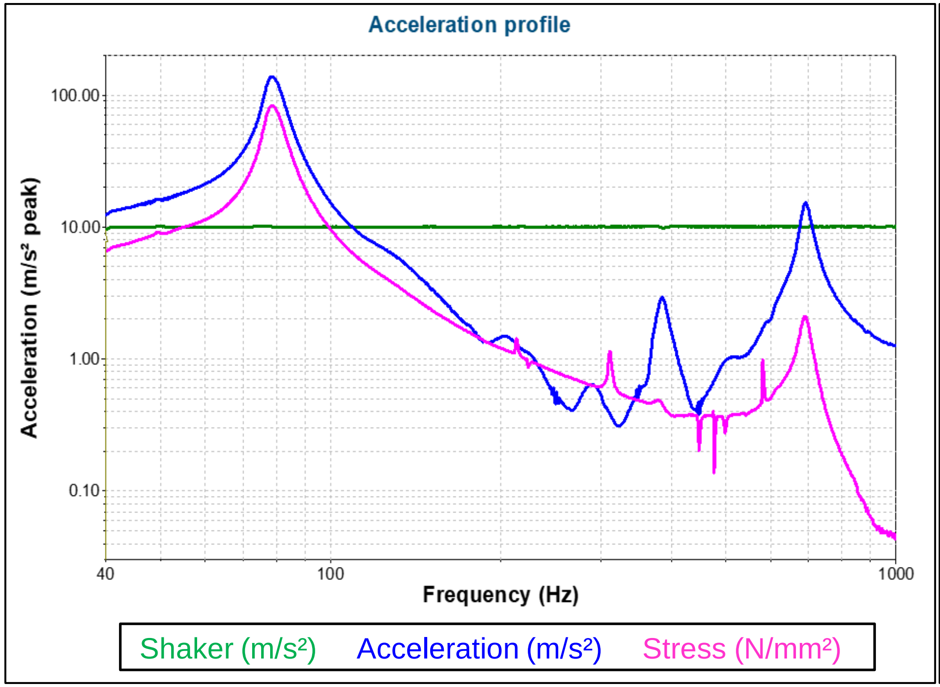


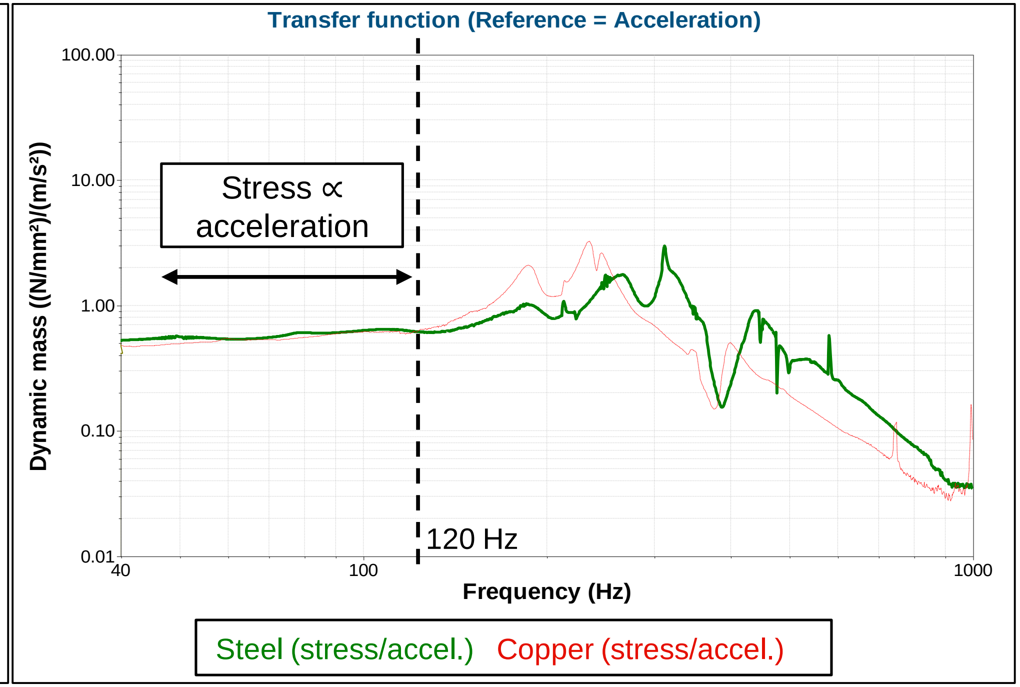
Materials used

- Structural steel and copper (ETP)

Parameter 1: Experimental verification of stress proportionality

- Results from frequency sweep tests
  - Stress measurement with strain gauges
  - Acceleration measurement at free end with accelerometer
  - Transfer function analysis

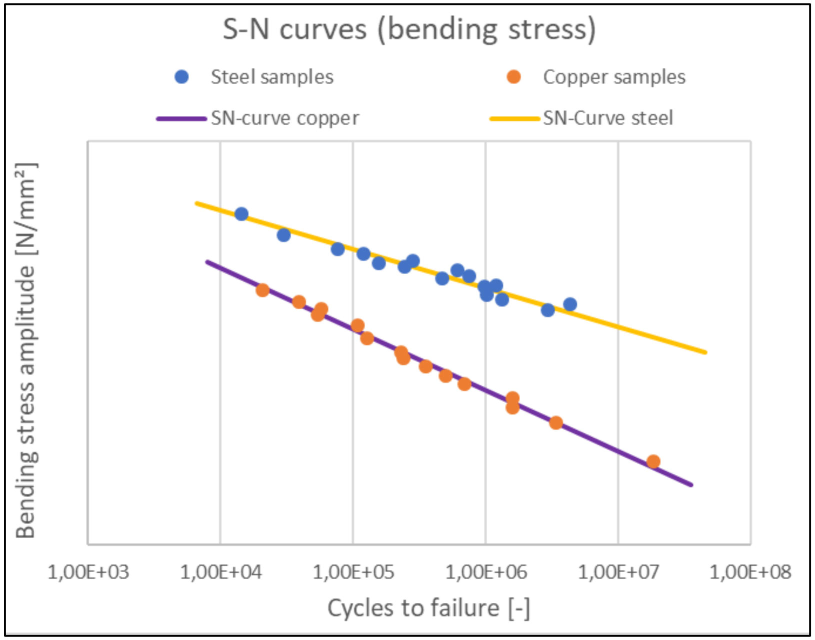




- Resonance at first natural frequency (around 80Hz)
- Stress is proportional to acceleration (till 120Hz) !

Parameter 2: Slope of S-N curve of a material

- Damage accumulation (Palmgren/Miner), slope b of S-N curve is an important input parameter
- Experimental determination of S-N curves



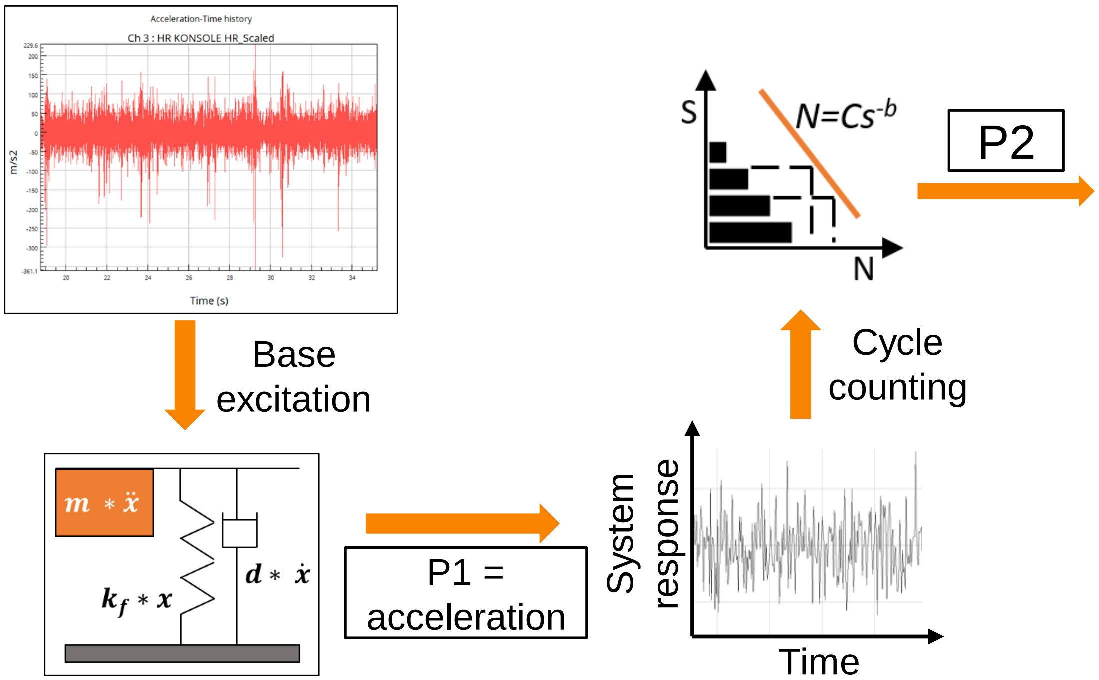
- Comparison with values from literature:

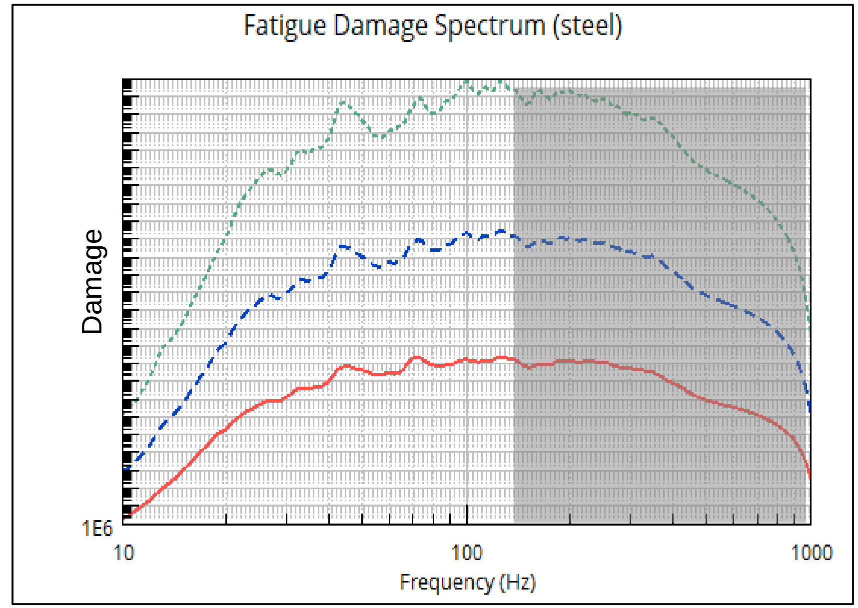
Standard/Norm	FKM	MIL-STD-810H	Experimental
Slope of S-N curve (steel)	5	7.5	10.4

Reference/Literature	National Bureau of Standards, USA	Deutsches Kupferinstitut	Experimental
Slope of S-N curve (copper)	6.9	7.4	6.6

Effect of S-N curve slope on FDS

- Measured acceleration time history ⟶ Fatigue Damage Spectrum plot





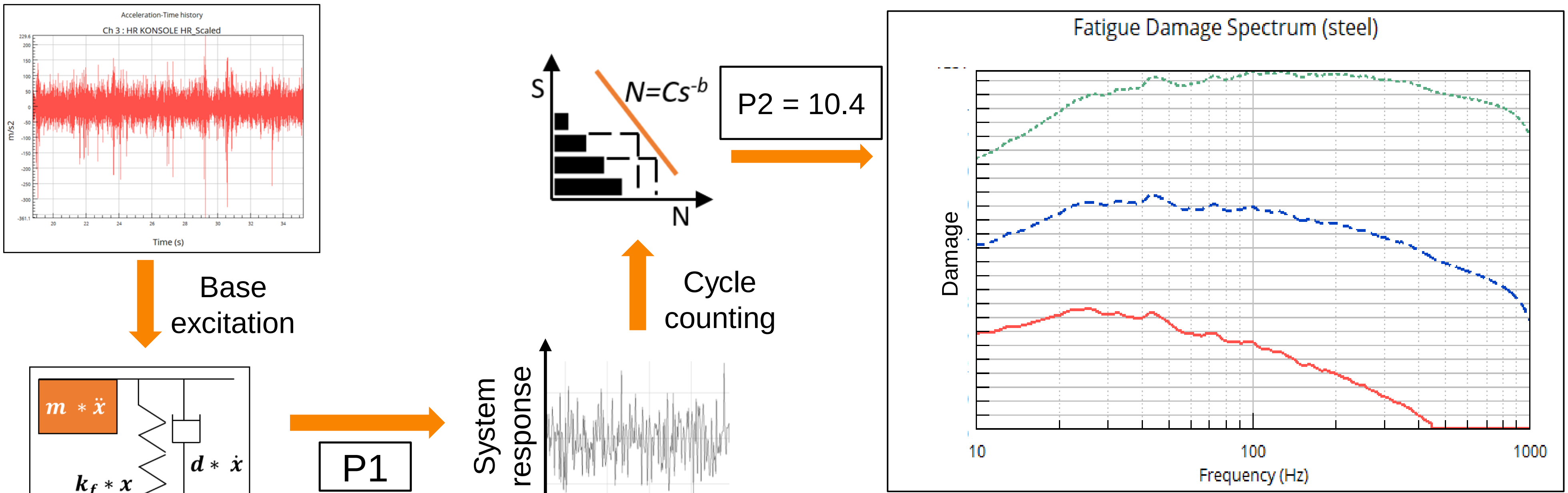
Legend

Marker	Title
	Ch 3 : FDS (acceleration), S-N curve slope 5 : Damage
	Ch 3 : FDS (acceleration), S-N curve slope 7.5 : Damage
	Ch 3 : FDS (acceleration), S-N curve slope 10.4 : Damage

- The curvature of the FDS plots for each S-N curve slope changes
- Higher slope value indicates more conservative values

Effect of choice of proportionality factor on FDS

- Measured acceleration time history ⟶ Fatigue Damage Spectrum plot



Legend

Marker	Title
red solid line	Ch 3 : FDS (displacement), S-N curve slope 10.4 : Damage
blue dashed line	Ch 3 : FDS (velocity), S-N curve slope 10.4 : Damage
green dotted line	Ch 3 : FDS (acceleration), S-N curve slope 10.4 : Damage

- Trend of the FDS curve changes according to proportionality factor
- Choice of proportionality is critical at higher frequencies

Summary

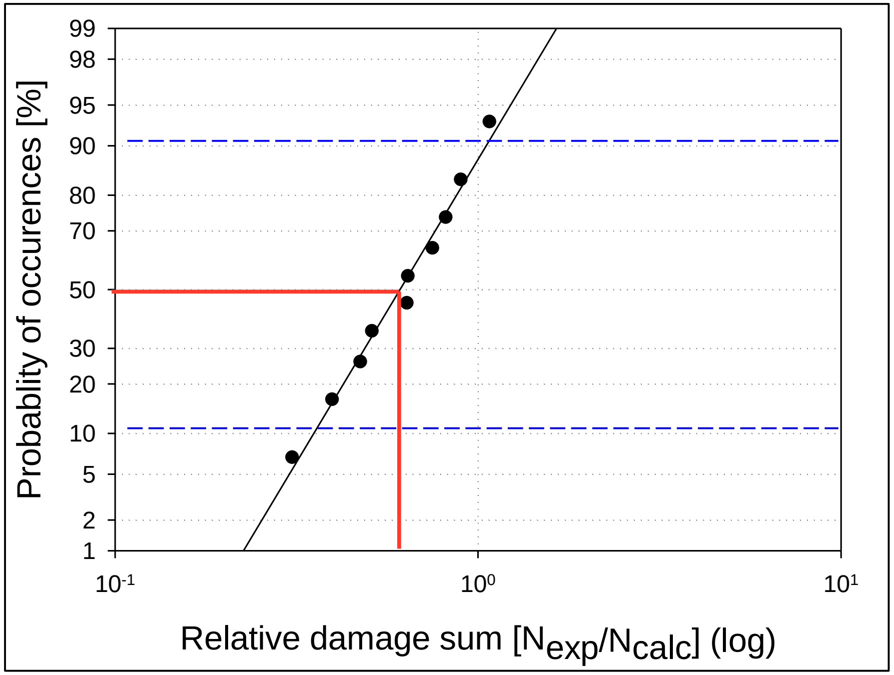
- FDS as a tool for accelerating tests.

- Every use-case is unique!
  - The choice of response type affects the plot of FDS
    - Stress is proportional to acceleration, velocity or displacement depending on the application and frequency range.
    - Transmissibility analysis between stress and vibrational parameters might be helpful to reveal the predominant proportionalities for certain frequency ranges.
  - Material parameters (S-N curve) has a strong effect on the calculation of FDS

- Alteration in damage spectrum (and eventually in the accelerated spectrum) due to these factors must be kept in mind.

Prospects

- Experimental and numerical investigation can reveal further prospects of test acceleration with FDS.
- Basis of comparison with **unaccelerated test results**: relative damage sum
  - Relative damage sum = $\frac{N_{Exp}}{N_{Calc}}$



- Bias (D_{50})= 0.8
- Spread ($\frac{D_{90}}{D_{10}}$)= 2.74
- Accelerated test results with assumptions of FDS parameters will lead to deviation of results.

Questions?

THANK YOU FOR YOUR ATTENTION!