TRACKED VEHICLE VIBRATION AND TAILORING OF ENDURANCE REQUIREMENT

Suitability of random-on-random vibration test as recommended in MIL-STD-810H is confirmed and a novel random-on-random simulation is proposed for response spectrum calculation

RISE Research Institutes of Sweden

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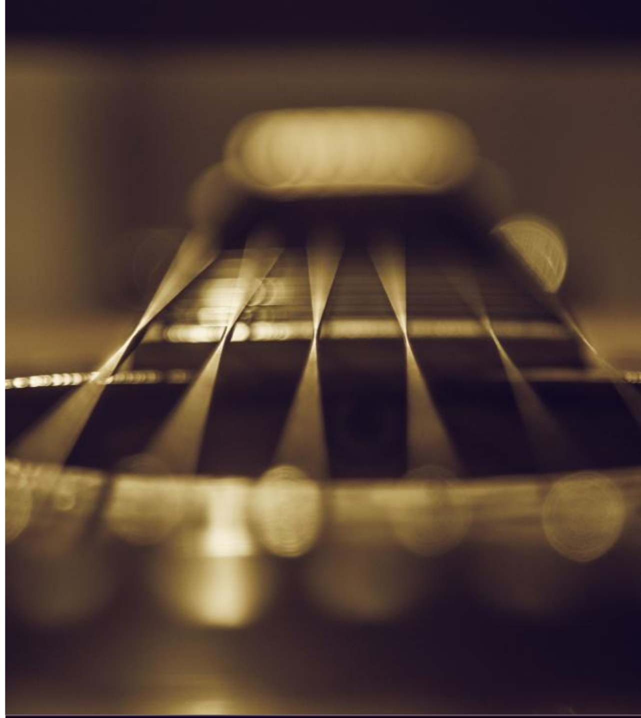
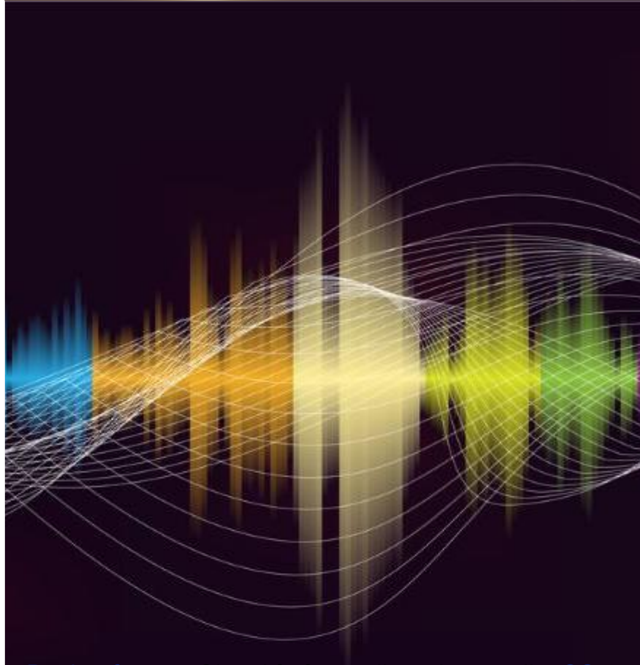




RISE Research Institutes of Sweden

- State-owned research institute with a mission to be a strong innovation partner to corporations and society
- 2700 employees offer unique expertise in a wide range of knowledge and application fields (1/3 with a PhD)
- 100 testbeds and demonstration facilities

Short facts about RISE Applied Mechanics

- 50 researchers, engineers, technicians and admin staff
- Node for solid and structural mechanics inside RISE
- Large experimental & simulation capabilities
- Expertise in shock & vibration integrity and reliability, with a unique seismic testing service

Example of load frame for material testing

Max force 1.2 MN

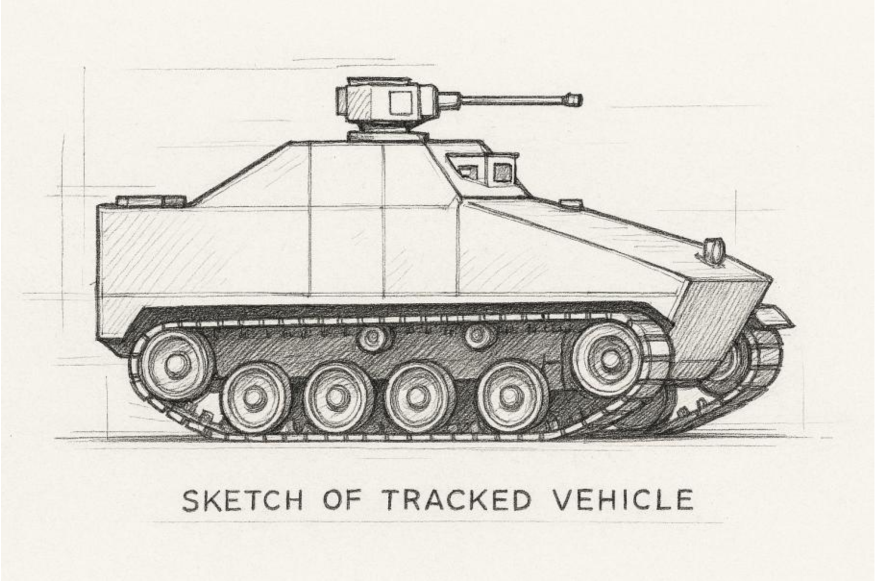
Test tailoring for equipment in a tracked vehicle

- RISE was contacted for a vibration test tailoring assignment, for equipment in a tracked vehicle
- Experiences from the assignment are presented

1. Assessment on the nature of tracked vehicle vibration
2. Method for response spectrum calculation (MRS/FDS) for NBROR test vibration (NarrowBand Random-On-Random)

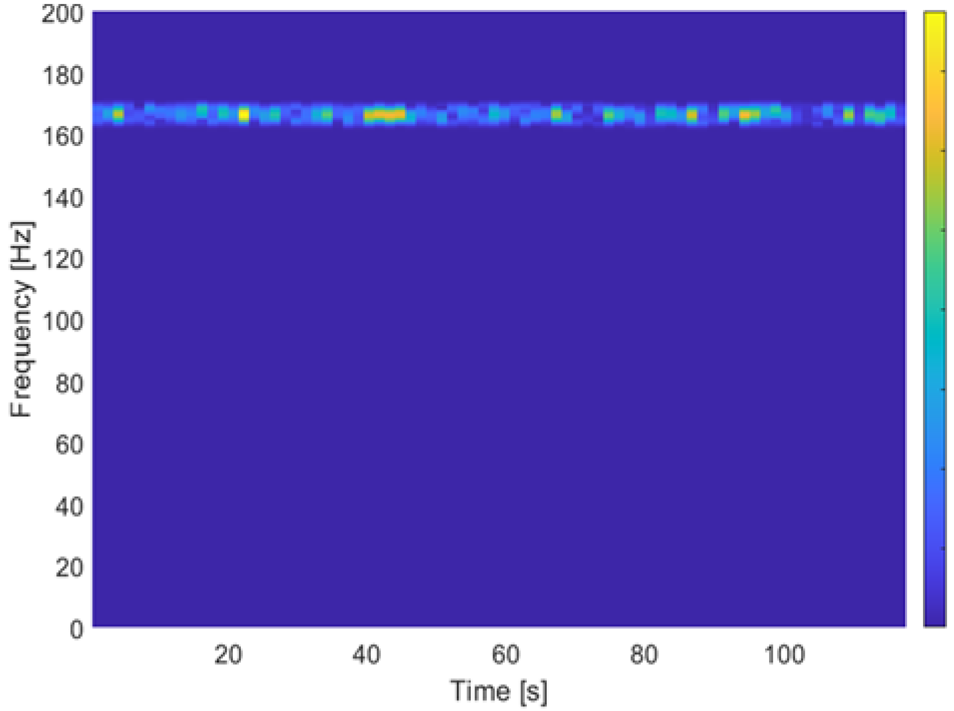
Tracked vehicle vibration

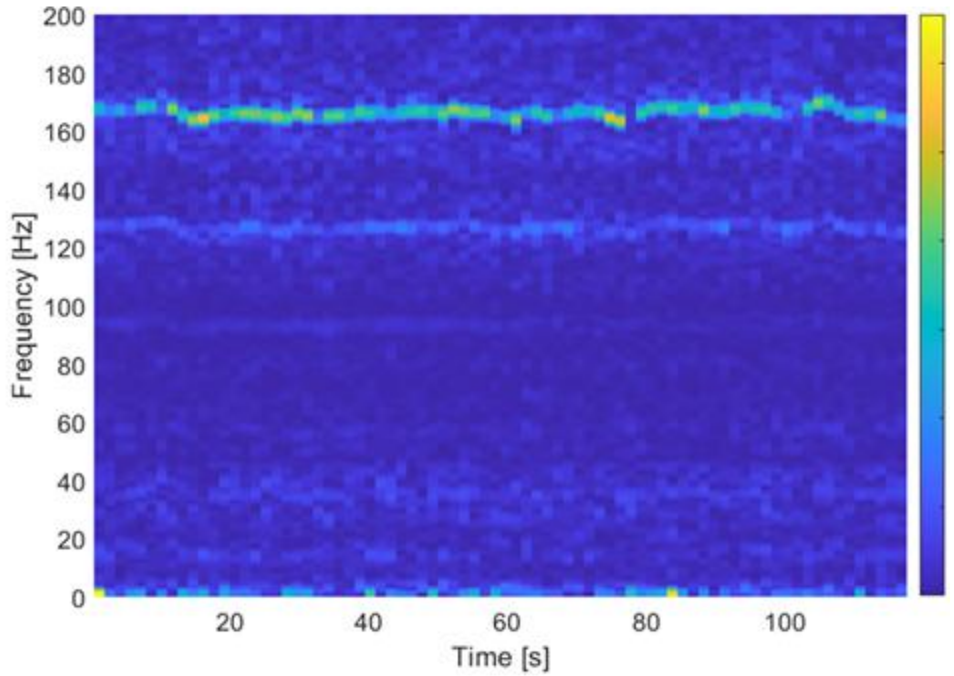
- Vibration from the ground surface when driving is strongly influenced by repeated impulses through the track pads
- At constant speed, one could argue that you would get a principal sinusoidal vibration with harmonics
- However, MIL-STD-810H, METHOD 514.8, ANNEX F is stating “dominant spectral spikes to be more nearly narrowband random in nature than sinusoidal”
- It also states: “A swept NBROR test is typically used to replicate tracked vehicle exposure”
- This recommendation was questioned and analysis was performed to evaluate the nature of vibration



Assessment of nature of vibration

- Sinusoidal or narrowband random?
- Let’s look at data from stationary conditions at constant speed
- Compare to a synthesized narrowband random sequence

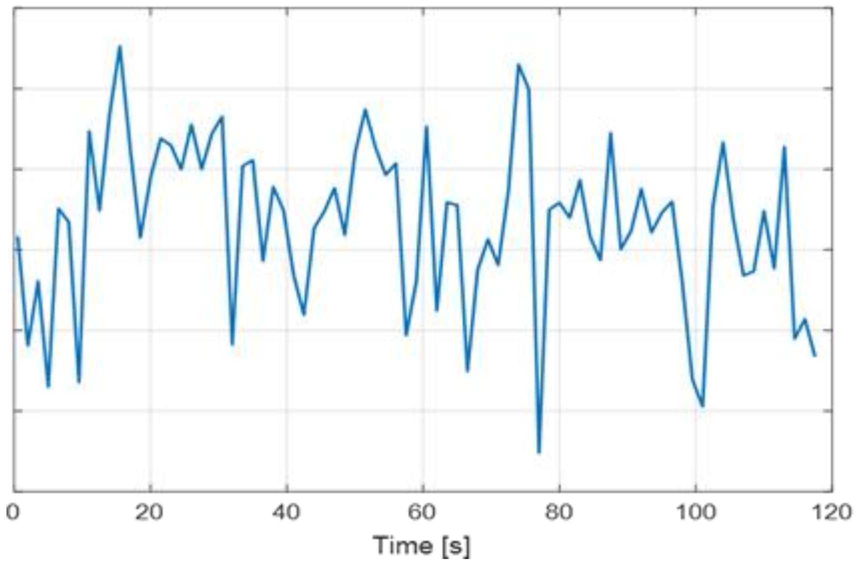


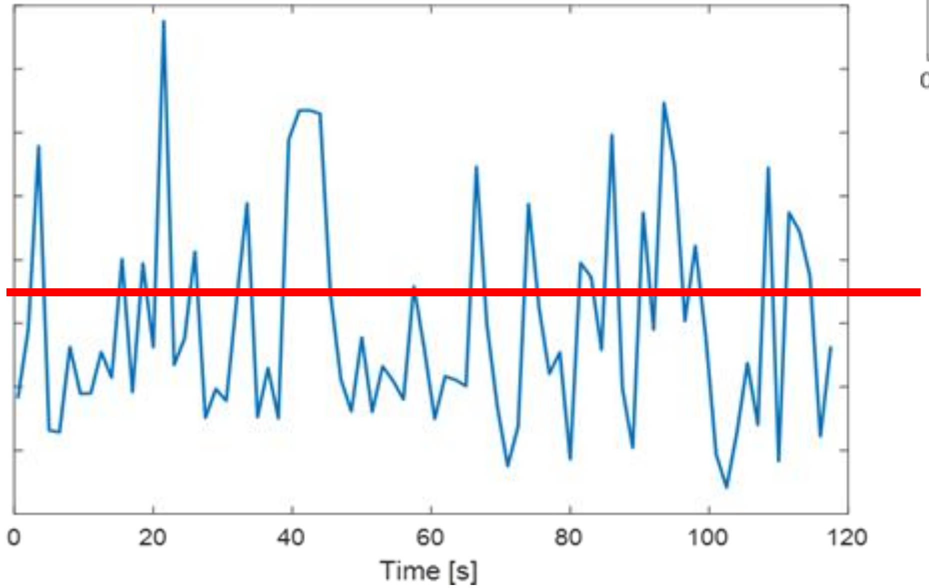


- Multiple short-time FFTs along a time scale presented in colour plots

Nature of vibration is random not sinusoidal

- Vibration amplitude value at principal track pad frequency vs time
  - Measured data to the right
  - Synthesised random ”chimney” below

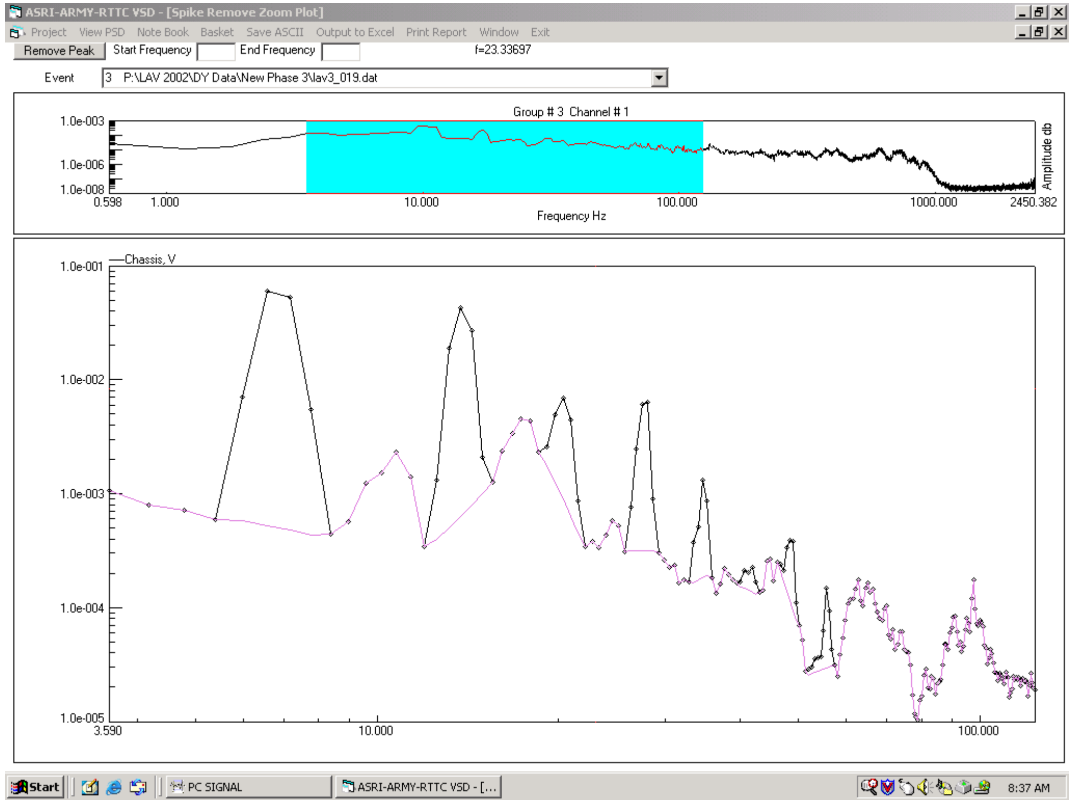




Sinusoidal instead of narrowband random would show constant amplitude

Field data acquisition

- Data from both slow speed sweeps and different constant speeds are beneficial
- Sweep data will give rms-amplitude as function of frequency for the principal track pad frequency and important harmonics.
- Constant speed data are needed for estimation of the background random vibration PSD outside the narrowband parts, as described in MIL-STD-810H (see picture)
  - The chimneys are easy to identify and erase

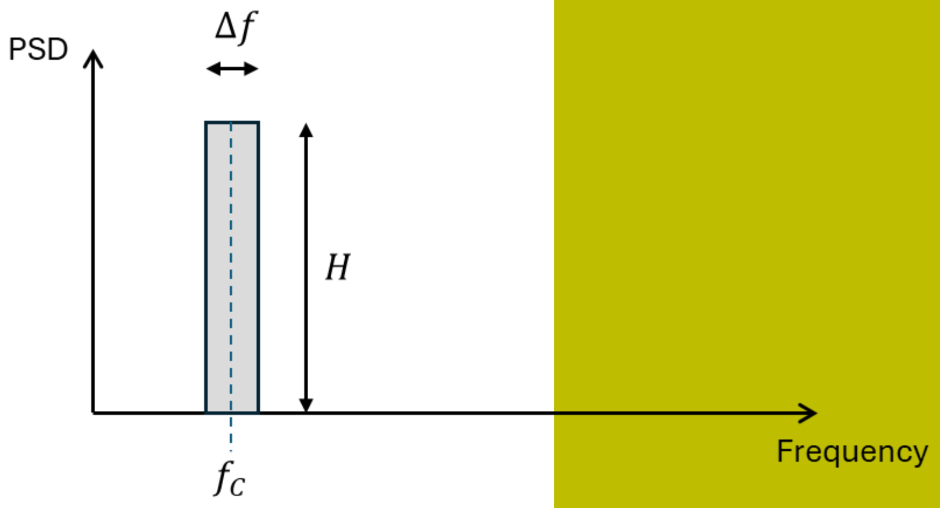


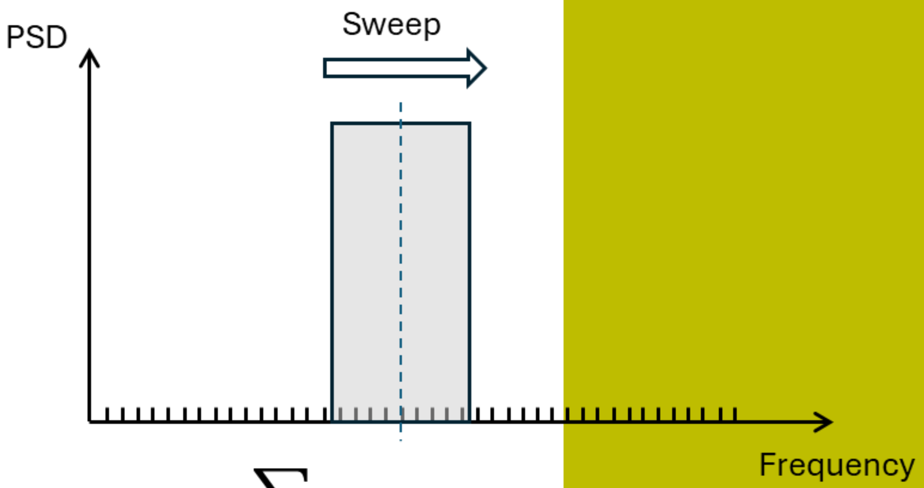
Tailoring for optimal test specification

- Determine how many track pad harmonics to identify as important
- RMS value as a function of center-frequency and bandwidth for the narrowband parts should simulate the principal track pad vibration and selected harmonics
- Determine background PSD by averaging data from each constant speed and make an envelope of results from all vehicle speeds.
- ’Lalanne’s approach’ using Maximum Response Spectrum (MRS) and Fatigue Damage Spectrum (FDS) is used for endurance equivalence
- Field data is used for FDS target calculation in time domain with weighting according to life profile, with respect to surface condition and vehicle speed
- NBROR is synthesised by parts and superposed to a test vibration simulation used for FDS calculation
- Simulation parts are adjusted individually based on FDS comparison, in an iterative process (don’t forget a safety margin)

Simulation of sweeping narrowband random

- The narrowband vibration is modeled as a rectangular ”chimney” with a center frequency f_C, bandwidth Δf, and height H.
- During a narrowband sweep, the center frequency varies over time, either linearly or logarithmically, depending on the selected sweep rate.
- The chimney height is continuously adjusted to ensure that the sweep maintains the correct RMS level.
- A sum-of-sinusoid approach with randomized phase is proposed to synthetize a random vibration that satisfies a moving chimney model
  - A random phase is assigned to each sinusoid (only once).
  - At each time instant and corresponding f_C, all sinusoids within Δf are summed. Spectral lines outside the chimney (Δf) have zero amplitude and are therefore excluded from the summation.
  - As the chimney sweep through the frequency range, sinusoids are continuously replaced by new ones.





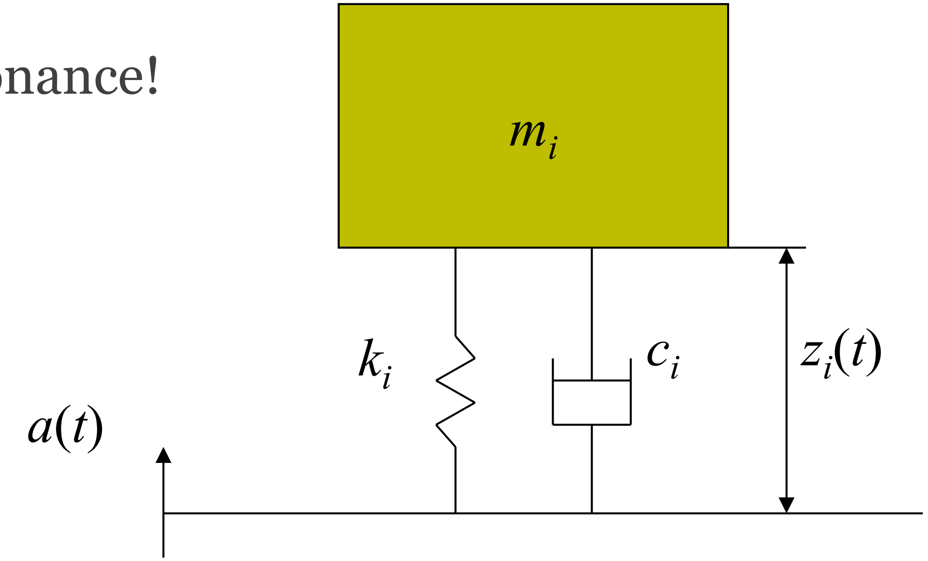
$$x(t_n) = \sum_m A_m \sin(2\pi f_m t_n + \alpha_m)$$

Definition of FDS and MRS

- Similar approach as when Shock Response Spectrum was proposed, for description of earthquake severity
- evaluation of effect from excitation, $a(t)$, on SDOF-systems with natural frequencies $f_i = f_1 + i \cdot \Delta f$, $i = 0,1,2,\ldots,N$

simple model of a resonance!

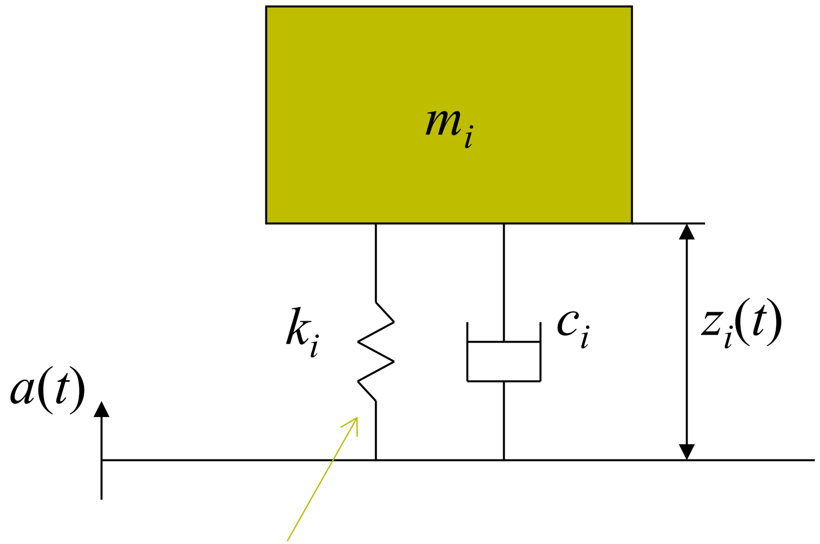
$$f_i = \sqrt{\frac{k_i}{m_i}}$$



Definition of MRS and FDS

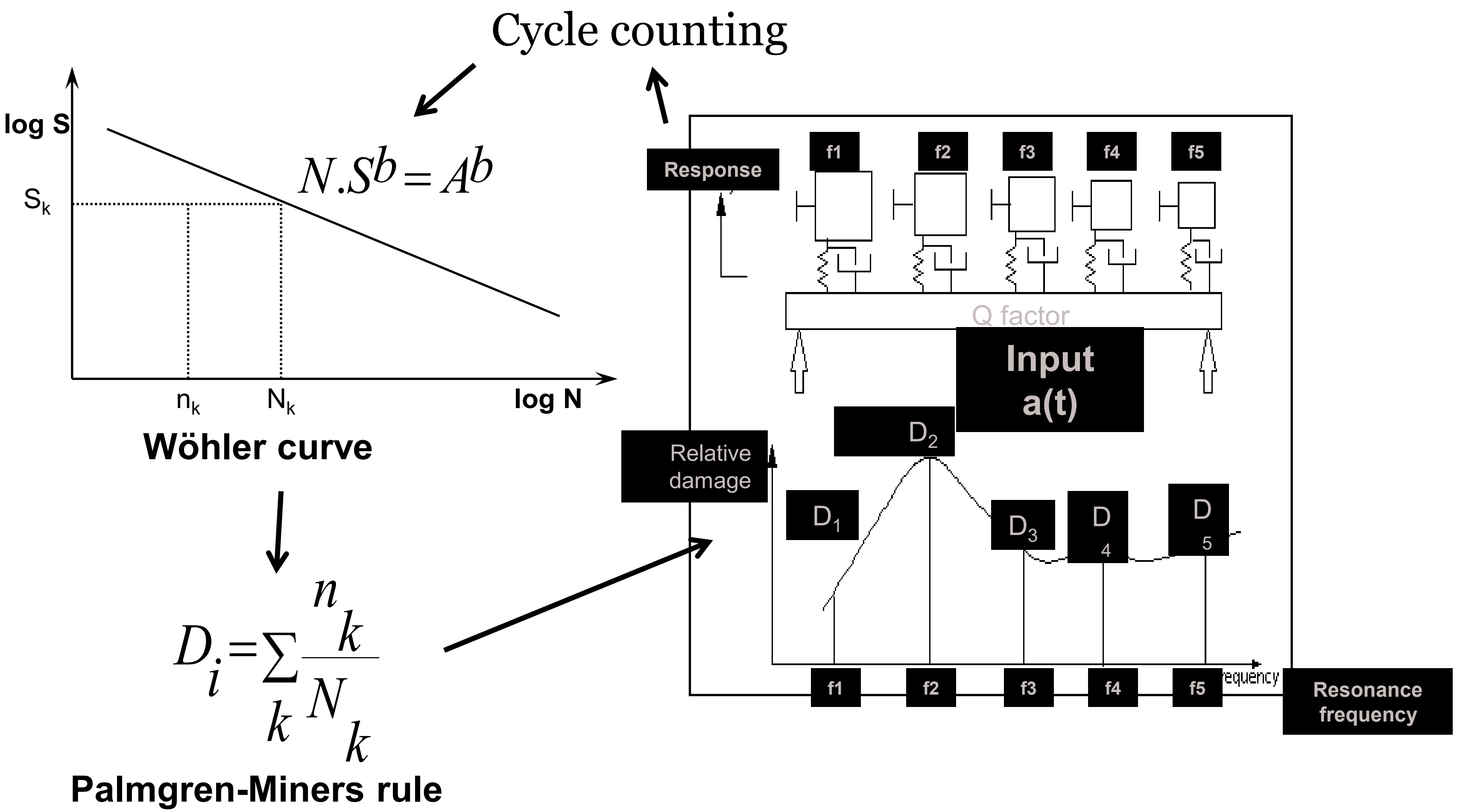
Following steps are taken for SDOF system i:

1. Relative displacement response, $z_i(t)$, is calculated
2. MRS
   - $\mathrm{MRS}(f_i) = (2\pi f_i)^2 * \max_{0<t<T}(|z_i(t)|)$
3. FDS
   - Extraction of rainflow cycles from $z_i(t)$
   - $\mathrm{FDS}(f_i)$ = fatigue damage based on linear damage accumulation (Palmgren-Miner) – a relative measure



Spring stress is proportional to $z_i(t)$

Fatigue Damage Spectrum



MRS/FDS for NBROR via synthesised time-series

- Lalanne developed analytical functions for approximate estimates of MRS and FDS directly from the PSD properties (moments) of a stationary random vibration
- A similar frequency domain calculation from a non-stationary random vibration with sweeping chimneys would be very complicated
- Instead, the calculation of MRS and FDS is made on long synthesised time-series outcomes from the random vibration with sweeping chimneys
- The generation of only a 10 minute NBROR outcome requires considerable computation time → a better FDS estimate is achieved by calculation of three independent outcomes that are shorter and taking the FDS mean value at each natural freuquency.

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MRS/FDS for SOR in the frequency domain

- A frequency domain calculation from a sine-on-random vibration can be done quite easily, if the PSD level is low in the frequency range of the sweeping sinusoid
- SOR FDS then approximates the envelop of the separate FDS from the random vibration PSD and the FDS from the sinusoidal sweep, except for frequencies close to the start and end frequency of the sweeping range
- SOR MRS approximates the sum of the separate MRS from the random vibration PSD and the MRS from the sinusoidal sweep, also at start and end frequencies of the sweep
- When the MRS sum is smooth around the start and end frequencies, you have a good vibration test regardless of the inability to compare FDS correctly

3-day course in advanced vibration analysis

- 19-21 Maj, in Göteborg
- More info and application form:

https://www.ri.se/sv/utbildning/kurs-i-vibrationsanalys

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Thank you!

- More questions are welcome!