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Major ADT Technologies in Vehicle Durability Engineering

Xudong Li, Ph.D.
Durability Application Engineer

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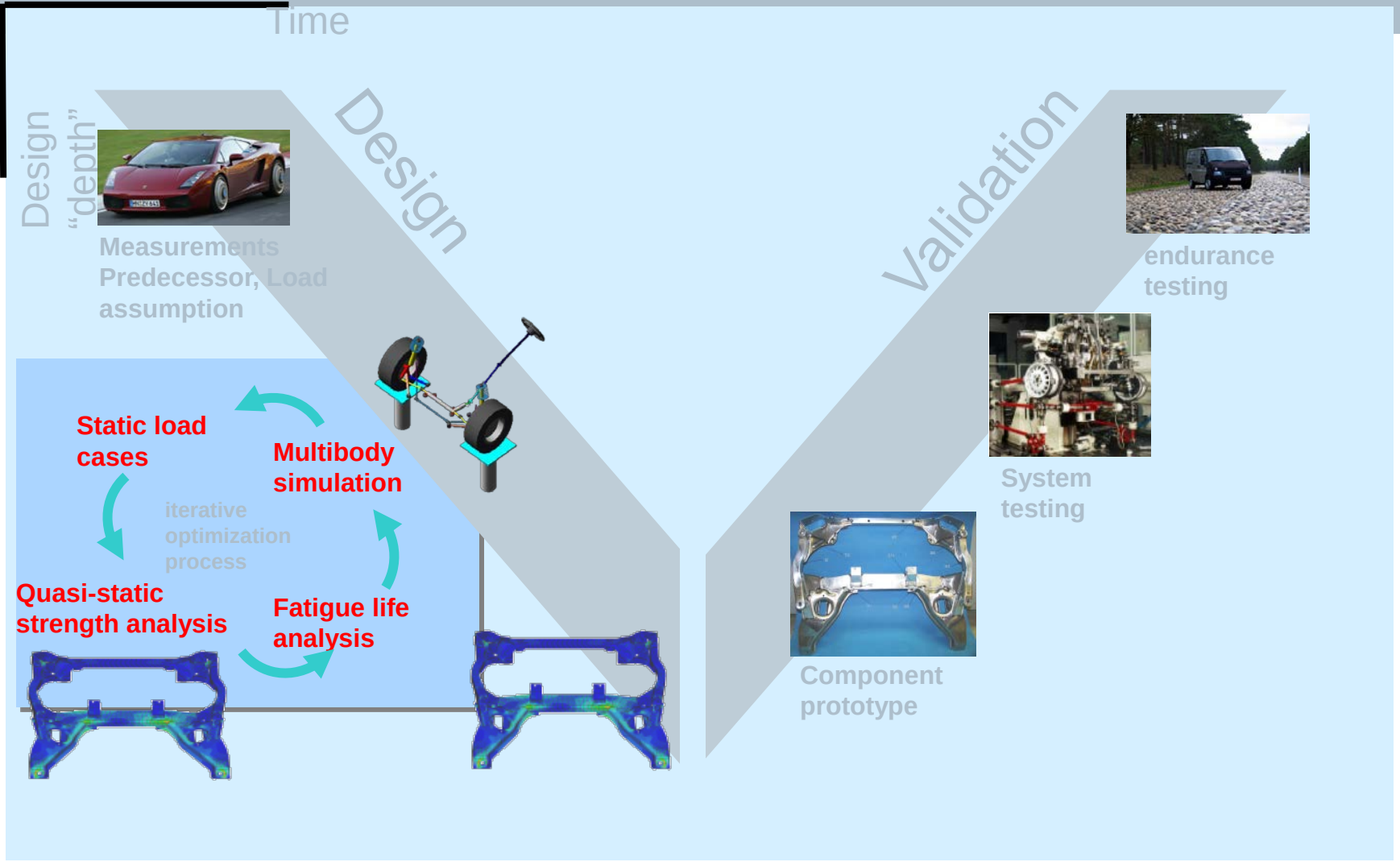
Durability engineering process – “To be” process
Optimizing for durability performance



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LMS durability engineering solutions
Optimizing durability performance

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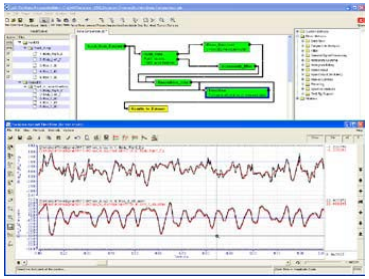
Understanding Operational loads → Target setting & Test Procedures → Design Optimisation Virtual Product Validation → Physical Product Optimisation & Validation → Final Product Test

Mobile data acquisition

LMS SCADAS Durability Recorder

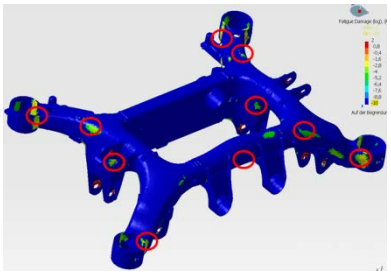
- True ruggedized
- Faster test preparation
- Wide variety of sensors
- Guaranteed high quality data
- Quick data validation on test track



Data analysis

LMS TecWare

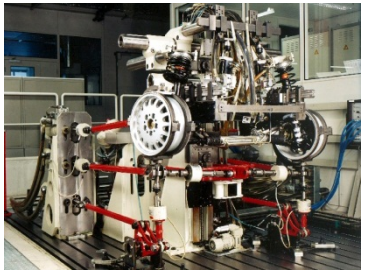
- Automate reduction and interpretation of vast amounts of measured load data
- Develop accelerated test procedures that reflect typical usage profiles



Simulation

LMS Virtual.Lab Durability

- Assess durability performance on component and system level before committing to prototype testing



Laboratory shaker trials

IST RS LabSite

- Fast set-up, accurate and safe execution of tests for reduced testing cost

Extensive field testing

LMS SCADAS Durability Recorder

- Ruggedness
- Long duration

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TecWare – Block Cycle Testing

How can you accelerate a test ?

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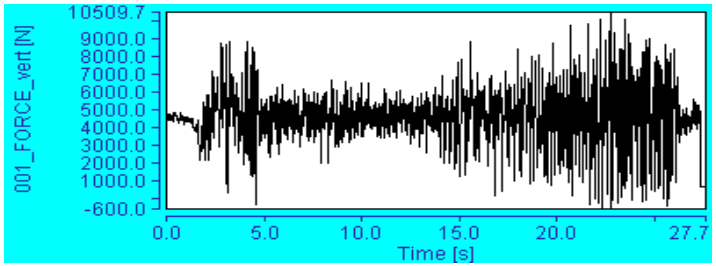
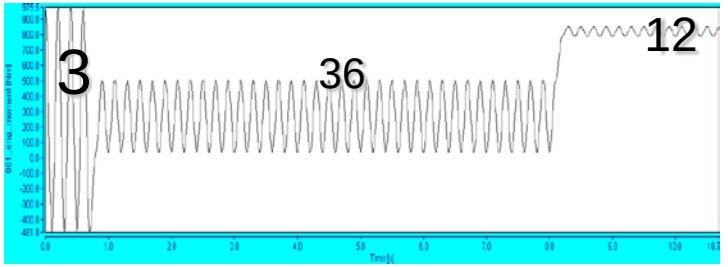
R2R - Design of Block Cycle Tests

Block cycle testing principle

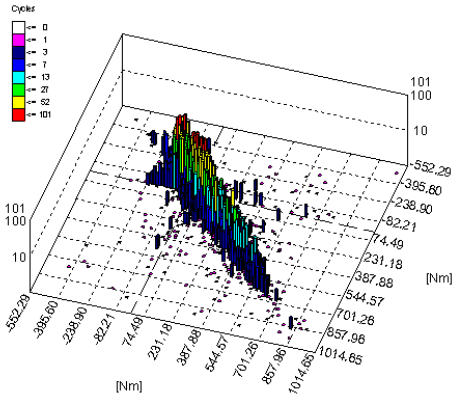
Original time series



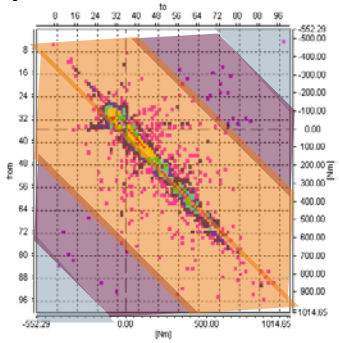
Damage equivalent
block cycle test



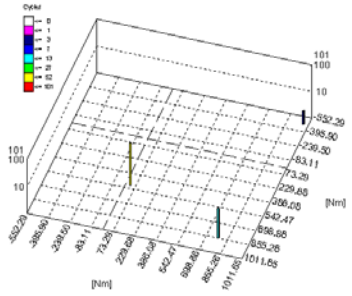
Rainflow matrix



Split RFM into n segments
of amplitude level:



Define 1 representative
CA level for each segment:



(standard SN curve
or user-defined)

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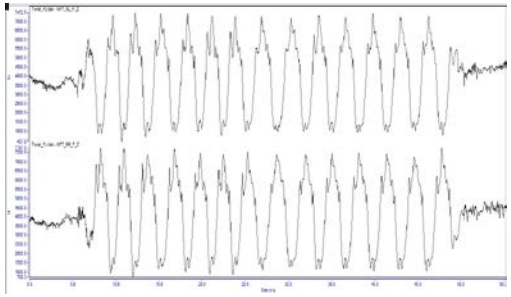
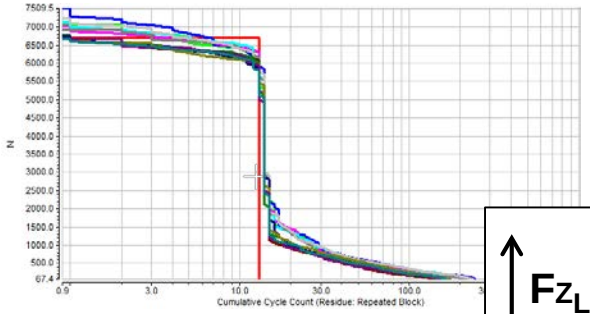
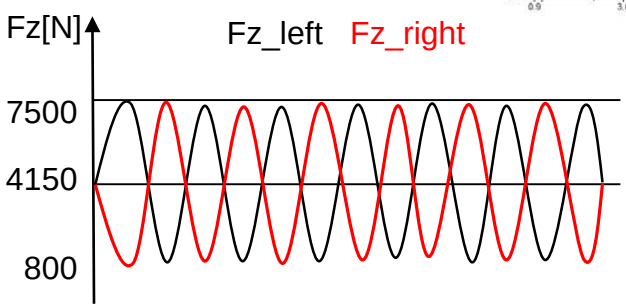
Test rig synthetic block load time series creation

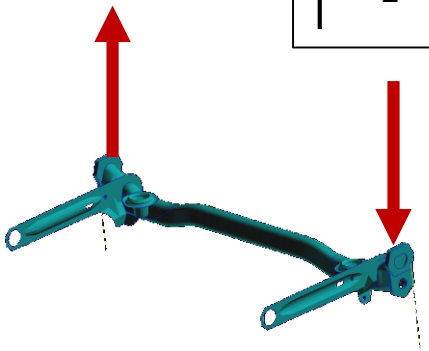




Deducted Torsion Rig Test:

- Load amplitude + mean value deducted from PG measurements
- 13 load cycles equivalent to 1 x Twist Road (PG)





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Mission Synthesis

How can you accelerate a test ?

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How it’s tested?

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Vibrations causing component failure

2015 F1 GP Hungary – Ferrari race incident

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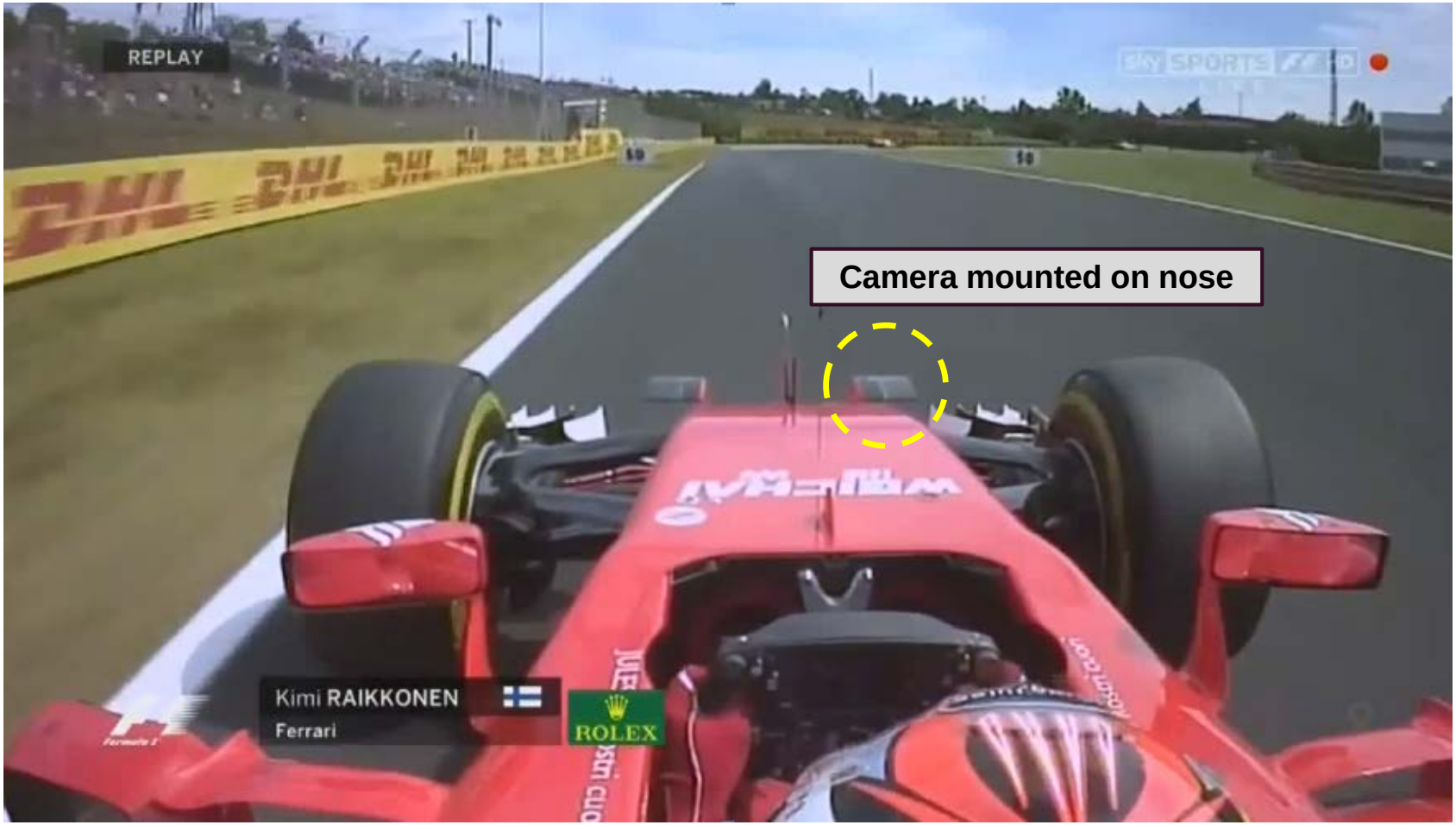
Vibrations causing component failure



2015 F1 GP Hungary – Ferrari race incident

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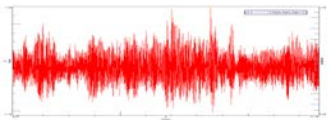
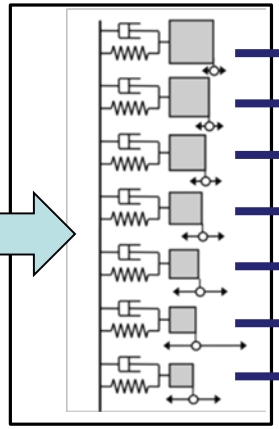
Analysis of the Damage Potential



Measurement
(base acceleration)

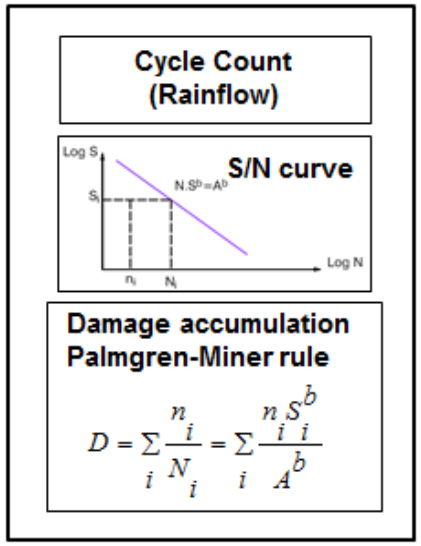
Supported excitation types: Timeseries, PSD, Sine sweep, Combined (= Sine-on-Random)

Input

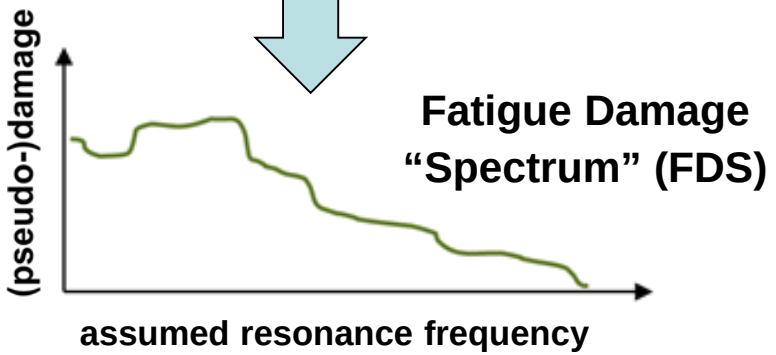


SDOF resonators
calculate responses for different assumed resonance frequencies

Responses
(relative displacements)



Fatigue Damage Calculations
(for each simulated SDOF response)



Fatigue Damage "Spectrum" (FDS)

The FDS is a tool for assessing the fatigue damage potential of an input vibration

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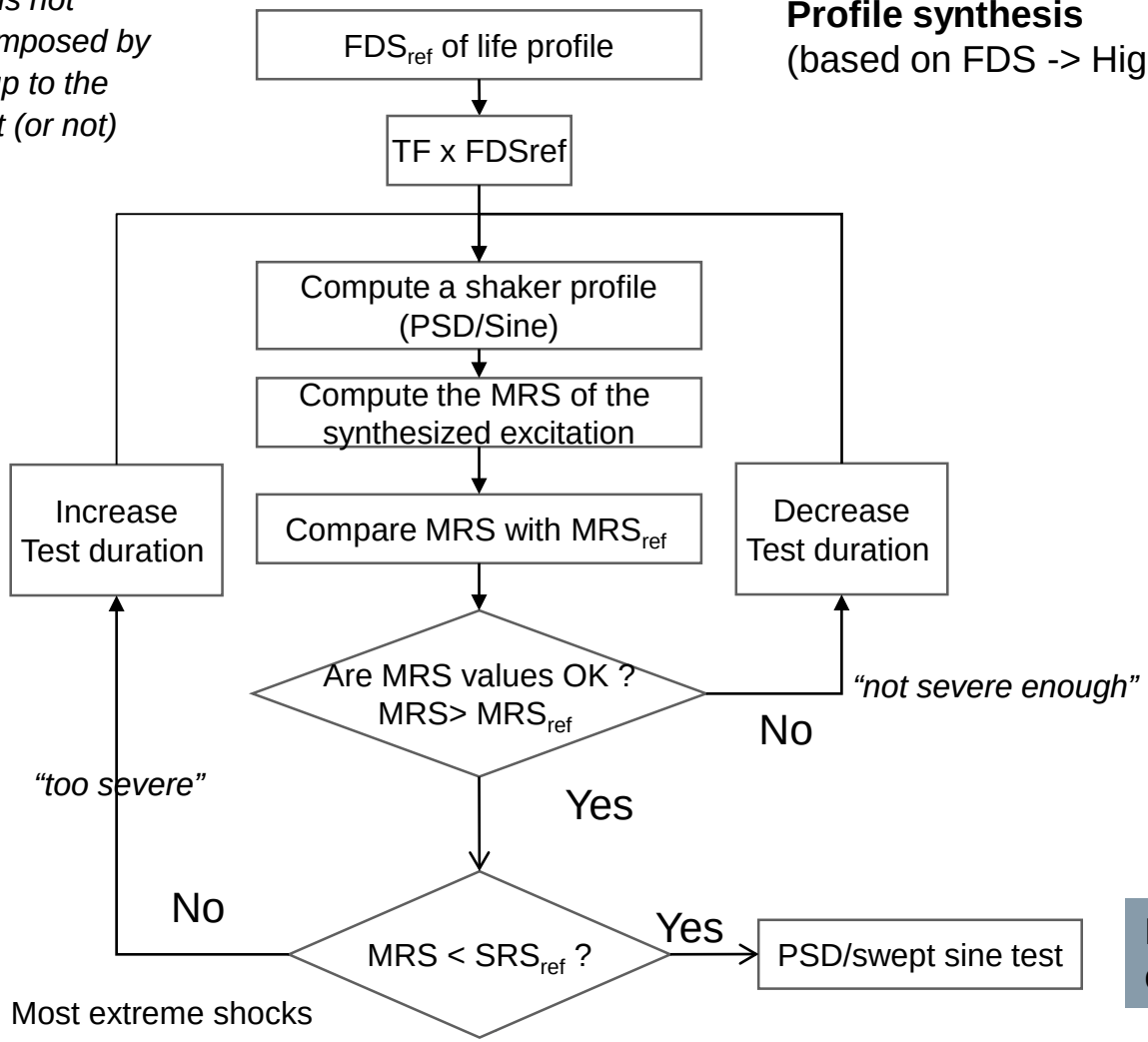
How to check & adjust test duration

This flowchart is not automatically imposed by the software: up to the user to follow it (or not)

Profile synthesis
(based on FDS -> High Cycle Fatigue)

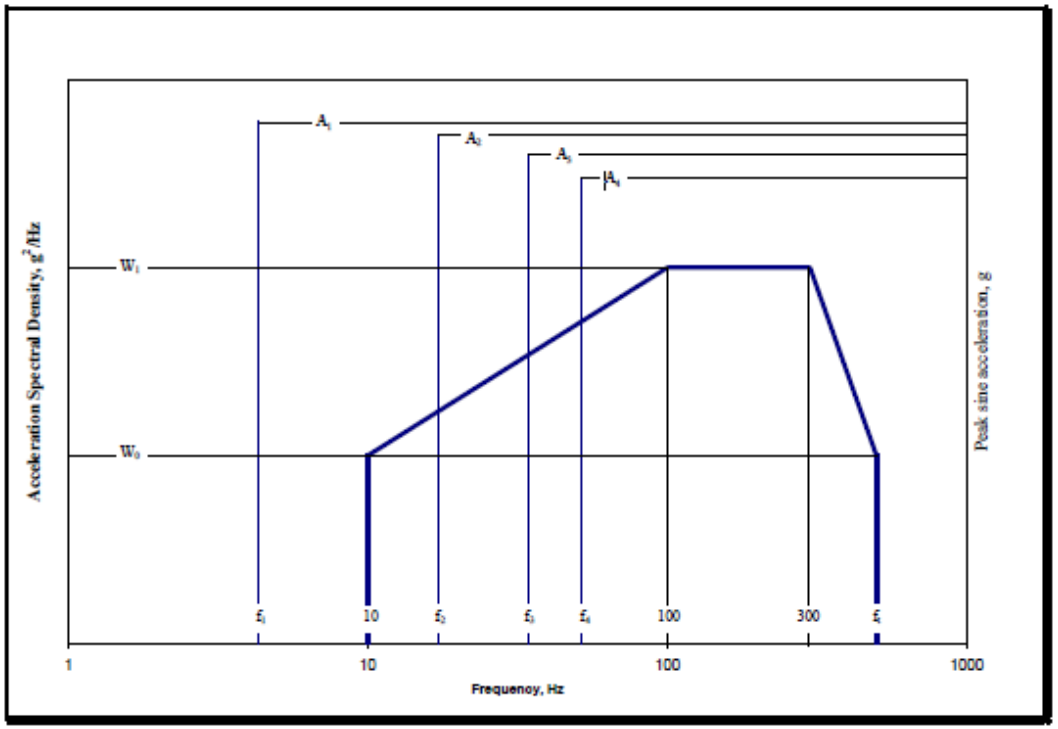


SRS$_{ref}$: Most extreme shocks encountered over lifetime

Long duration test to check for fatigue failure

Mission Synthesis vs Standards

Is standard sufficient to guarantee lifetime operation of the VHF-radio?



Parameters:

- Rotation speed main rotor = 392 rpm = 6.53 Hz
- #blades = 5
- Note: no tail rotor (NOTAR)

f1 = 6,53 Hz	A1 = 0,168 g
f2 = 32,67 Hz	A2 = 1,75 g
f3 = 65,33 Hz	A3 = 1,05 g
f4 = 98 Hz	A4 = 1,05 g

Sine-on-Random profile from MIL-STD-810 G

(random + 4 fixed sines)

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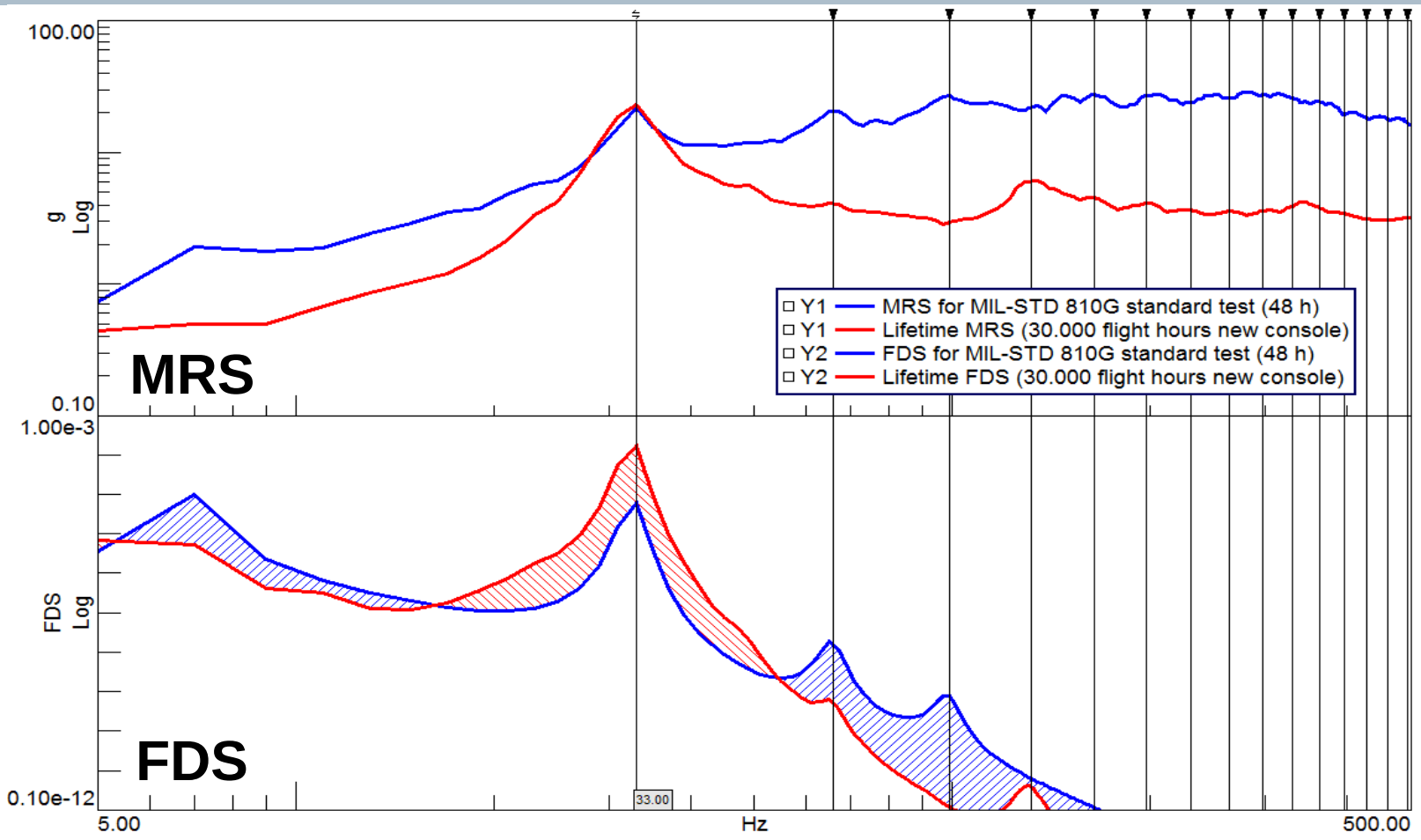
Comparison – MIL-STD vs Mission Synthesis



MIL-STD

Mission Synthesis

- MIL-STD: test duration 48 hours
- Mission Synthesis: 30.000 flight hours on new console

(+ also includes uncertainty factor)

eserved

Automotive example *(supplier perspective)*

- Different OEM customers may give different qualification specifications (even with different types: PSD, sine sweep,… and different test durations…)
  - How to compare different specifications?
  - How to design a single qualification test?

→ ***use FDS***

Component Supplier

e.g. engine coolant radiator

→ ***How to Test?***

OEM customer 1

→ Qualification profile specification 1

OEM customer 2

→ Qualification profile specification 2

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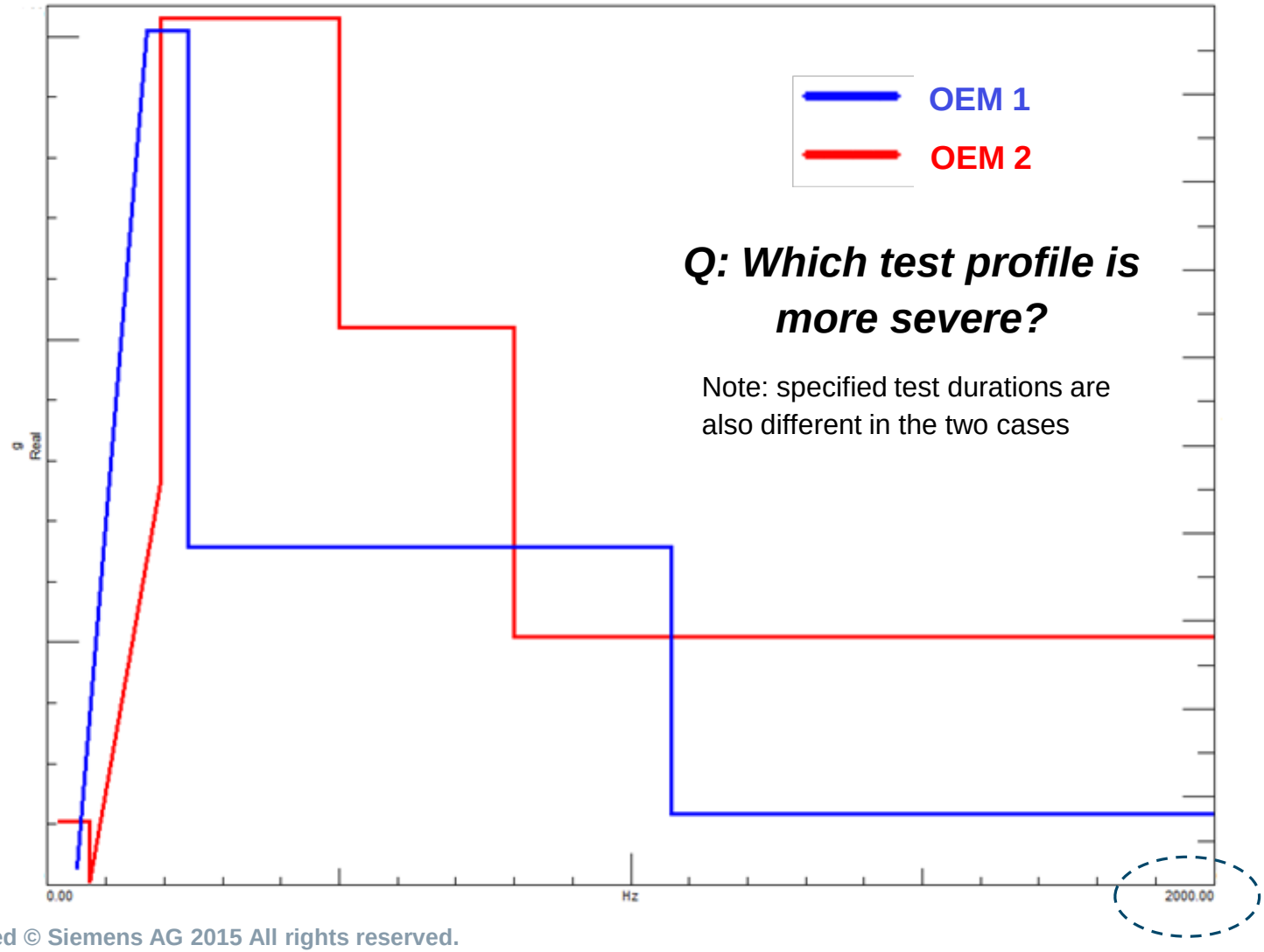
Real-life example – Sine sweep profiles OEM 1 vs OEM 2



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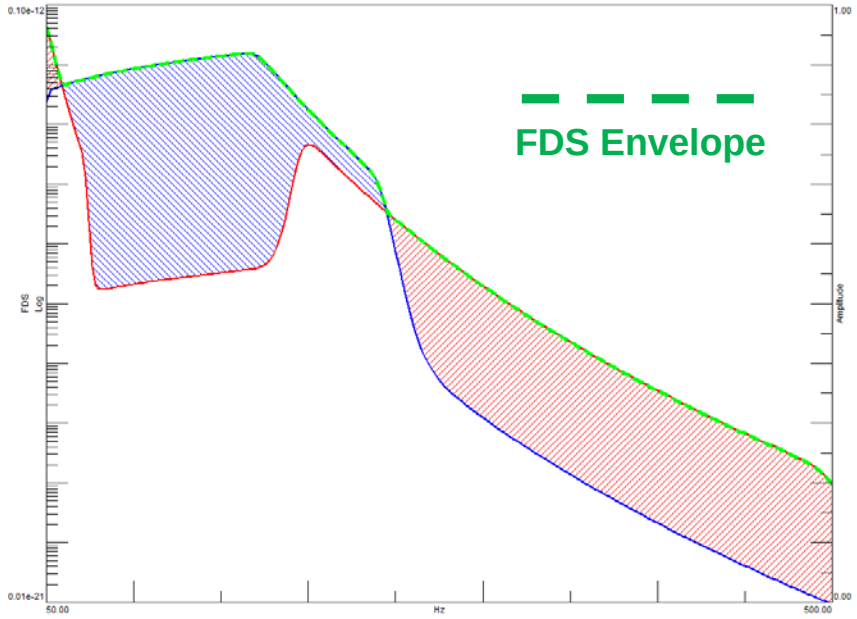
Synthesized qualification test



Synthesize test profile based on the FDS Envelope

Test Synthesis

- Vibration fatigue theories
- Basquin's law
- Specified test duration

If the component survives this synthesized qualification test, it fulfills the requirements of both OEMS

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Automotive example – Alternative *(OEM perspective)*

Apply Mission Synthesis
to determine vehicle mission FDS

OEM

Component Supplier 1

engine radiator 1
with qualification evidence

"Which supplier should the OEM choose?"

Component Supplier 2

engine radiator 2
with qualification evidence

- OEM uses FDS to compare qualification evidence of potential component suppliers
- Component should survive the real-life vehicle mission: qualification FDS > vehicle mission FDS

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TecWare – Rotating Rainflow Counting

How can you accelerate a test ?

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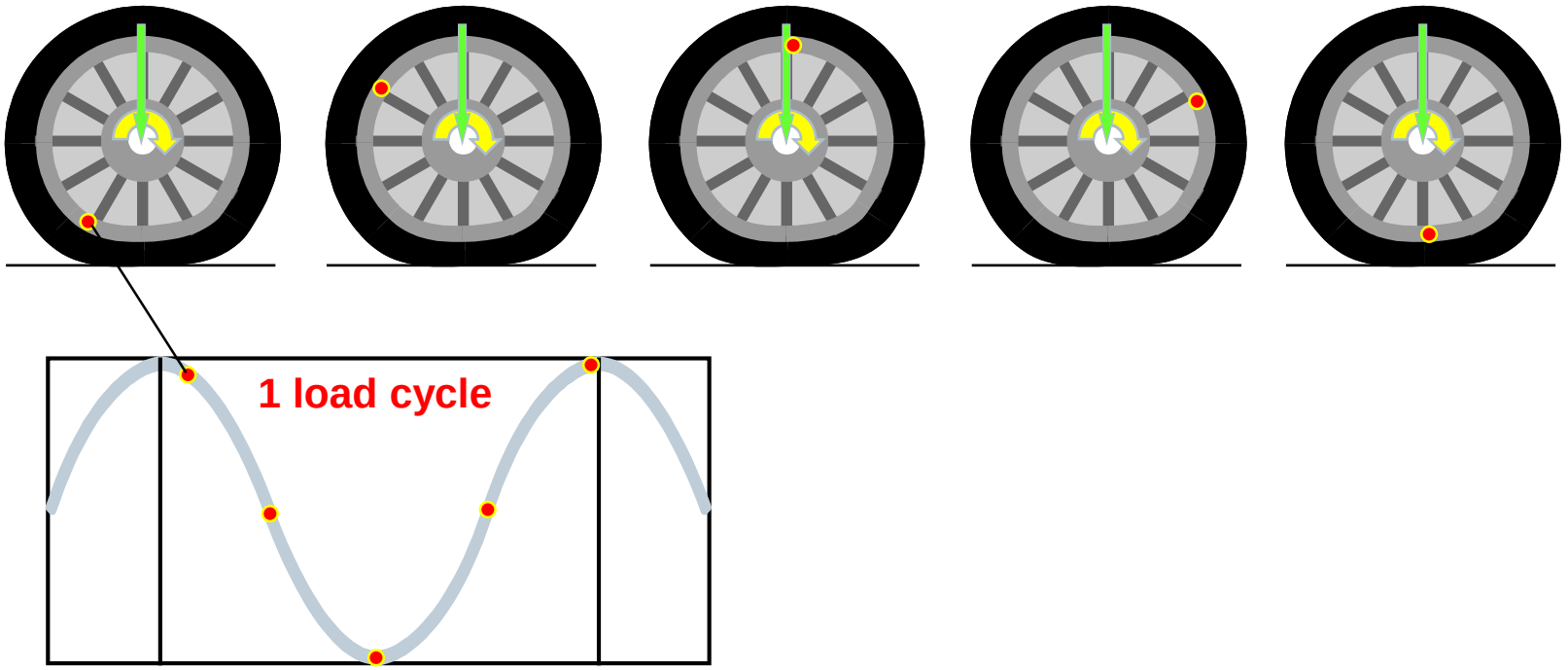
Rotating vs. Non-Rotating

A non-rotating part under constant load does not suffer any load cycles.

A rotating part under constant load may "see" load cycles. Examples:

- Gear wheels
- Rotating shaft with bending load



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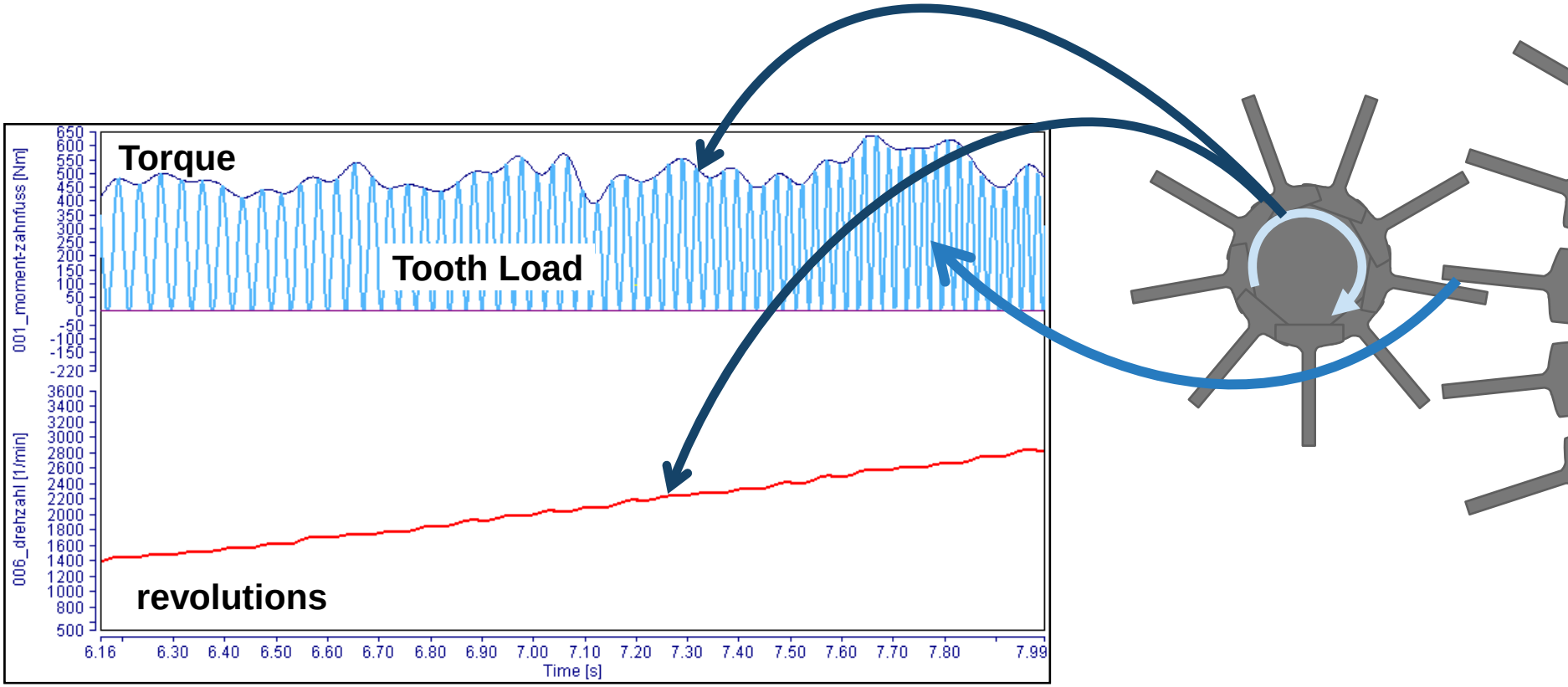
Load Data Analysis for Rotating Components



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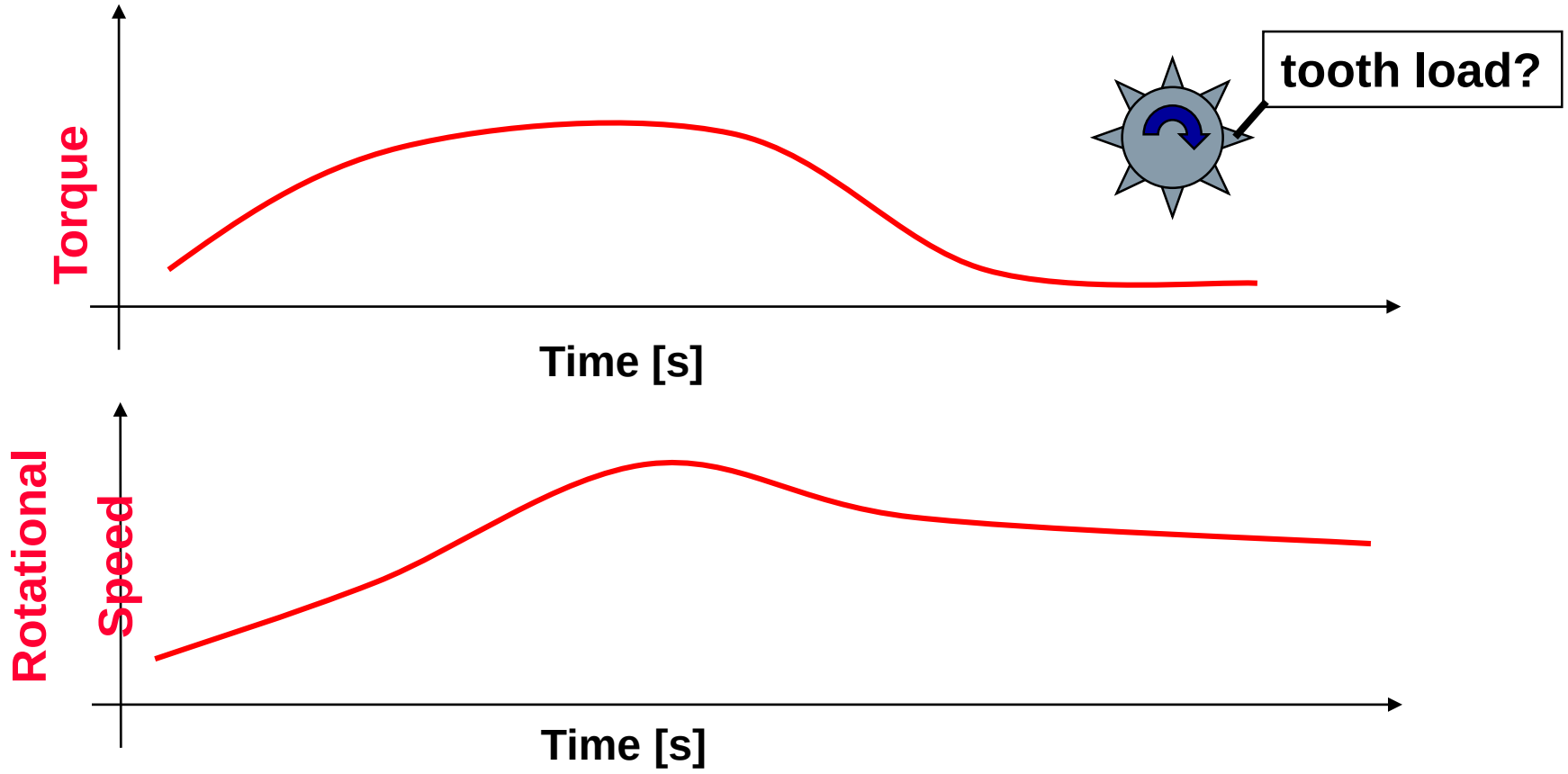
Taking Rotational Effects into Account



Each revolution creates (for the same sense of rotation) one load cycle.

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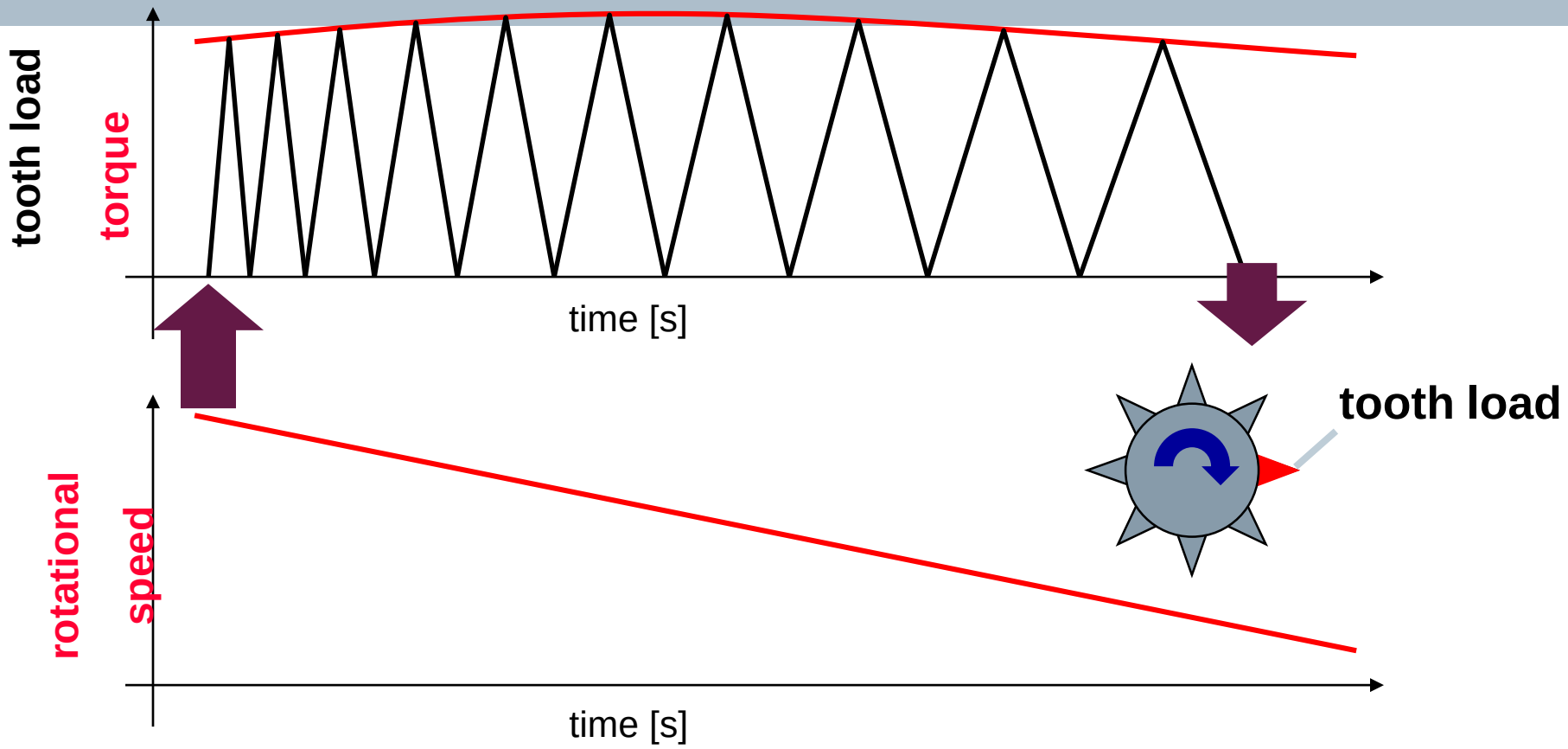
Rotating Rainflow Counting – Motivation



In each completed revolution the “reference tooth” touches its counterpart once. Only then it experiences the applied torque.

The tooth load is calculated by creating a turning point sequence connecting zero load with torque level, using the frequency defined by the corresponding RPM value.

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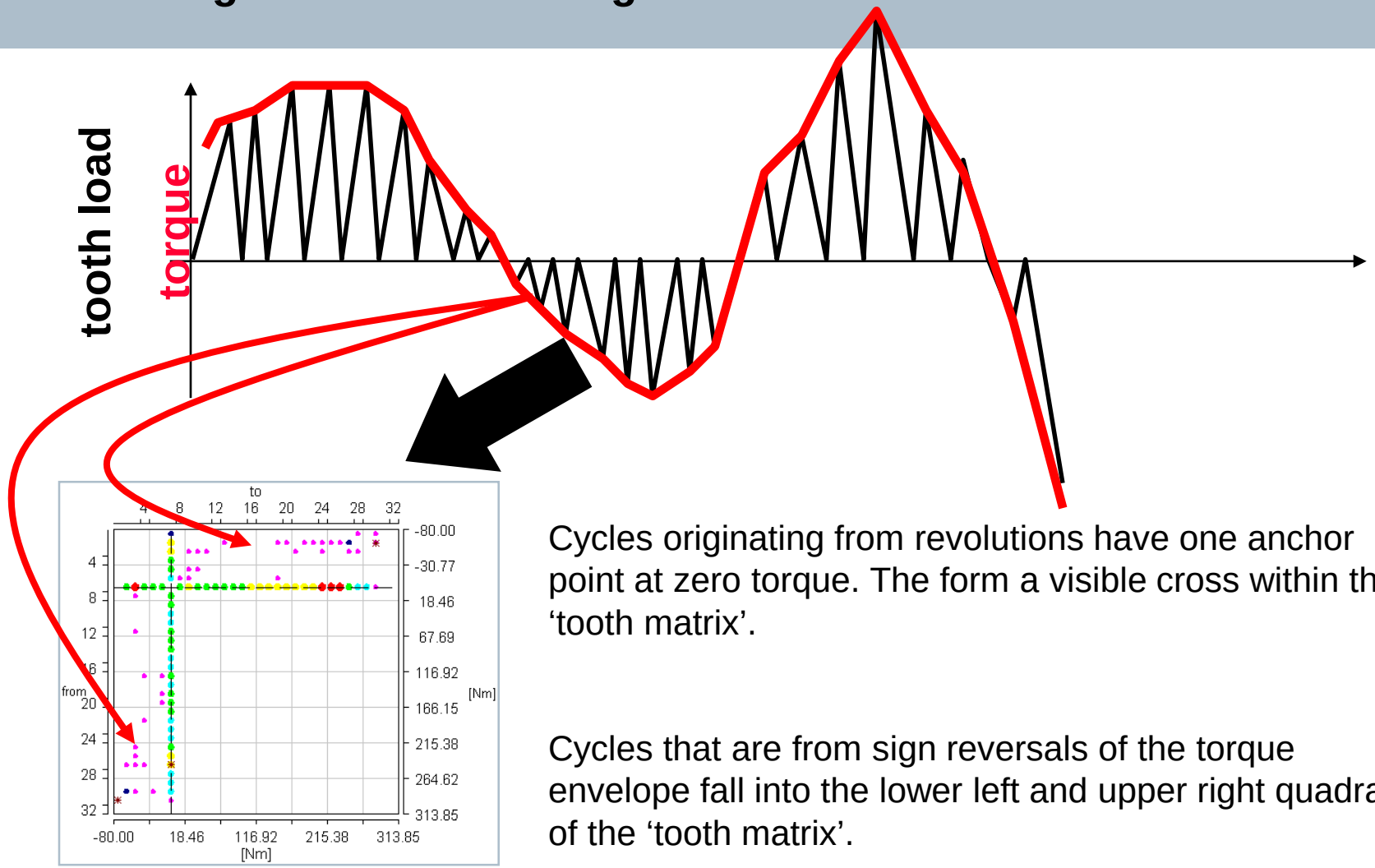
Rotating Rainflow Counting – Method



Cycles originating from revolutions have one anchor point at zero torque. The form a visible cross within the ‘tooth matrix’.

Cycles that are from sign reversals of the torque envelope fall into the lower left and upper right quadrant of the ‘tooth matrix’.

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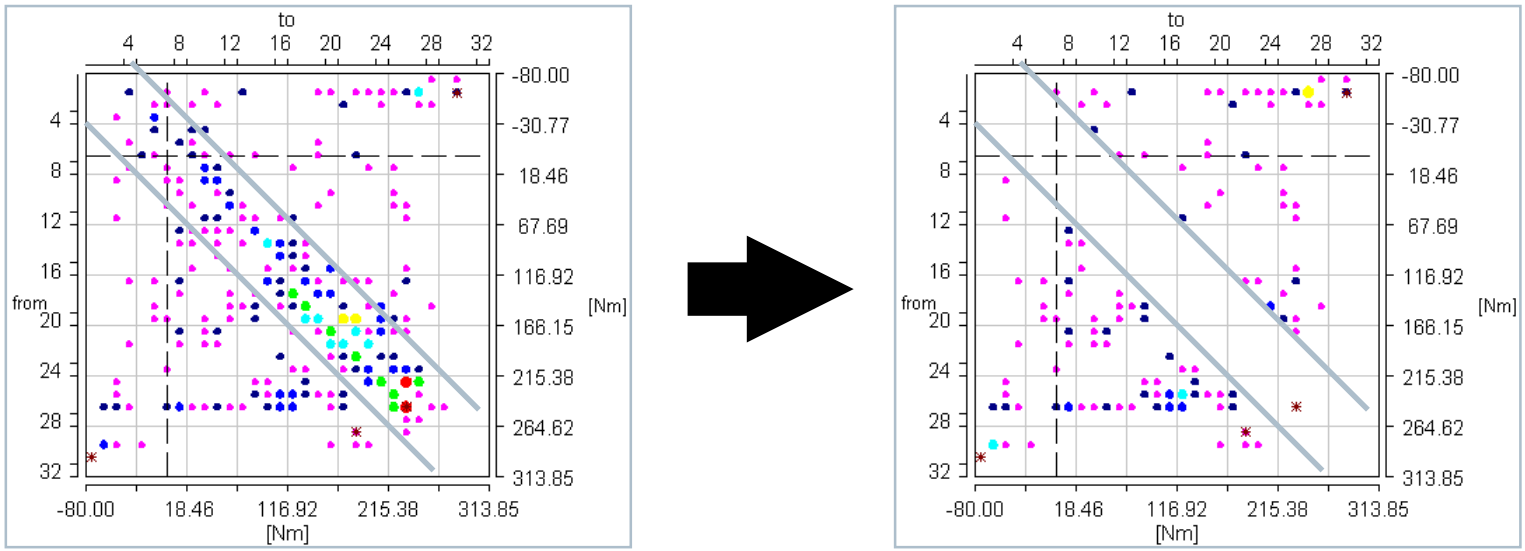
Rotating Rainflow Counting – Omission

Remove ‘small‘ load cycles from complete rotating rainflow files.

Same as doing it manually with RainEdit but less annoying.



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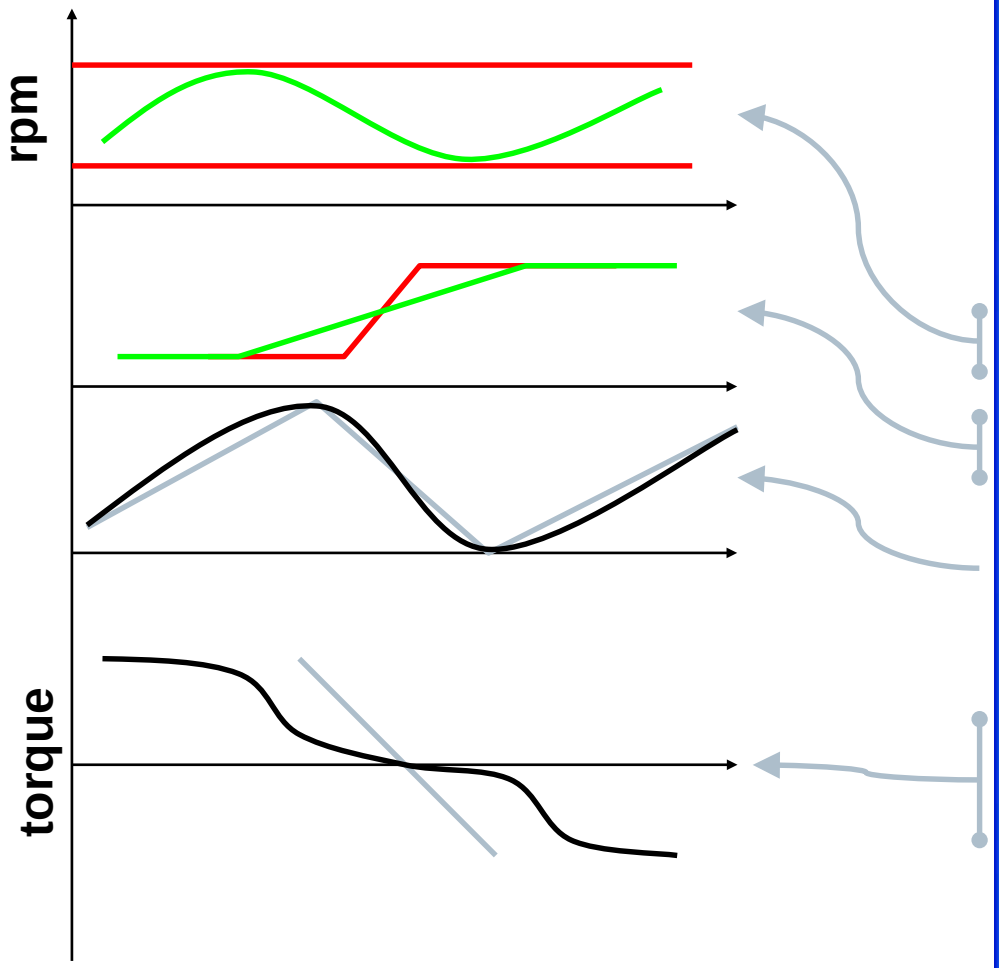
Rotating Rainflow Counting – Reconstruction Usage



Rotating Rainflow Reconstruction

Input for this method are pairs of shaft and tooth matrices. For every file one pair of matrices is supported by the method.
The method distinguishes between the shaft and the tooth matrix by matching channel name patterns (*Shaft*, *RotMo*).

Parameters:

Minimum rotational speed [rpm]	1500
Maximum rotational speed [rpm]	7500
Maximum allowed |slope of rotational speed| [rpm/s]	500
Maximum allowed |slope of torque| [x/s]	150
Sampling step size [s]	0.05
Reconstruction with arcs	on
Signal start and end at zero	off
RPM slope at start/end [rpm/s]	1800
Special treatment at torque zero	off
Lower torque boundary [Bins; 0-0.49]	0.2
Frequency limit at torque zero crossings [Hz]	4

Show log file

Show progress

use default values | Start | Close

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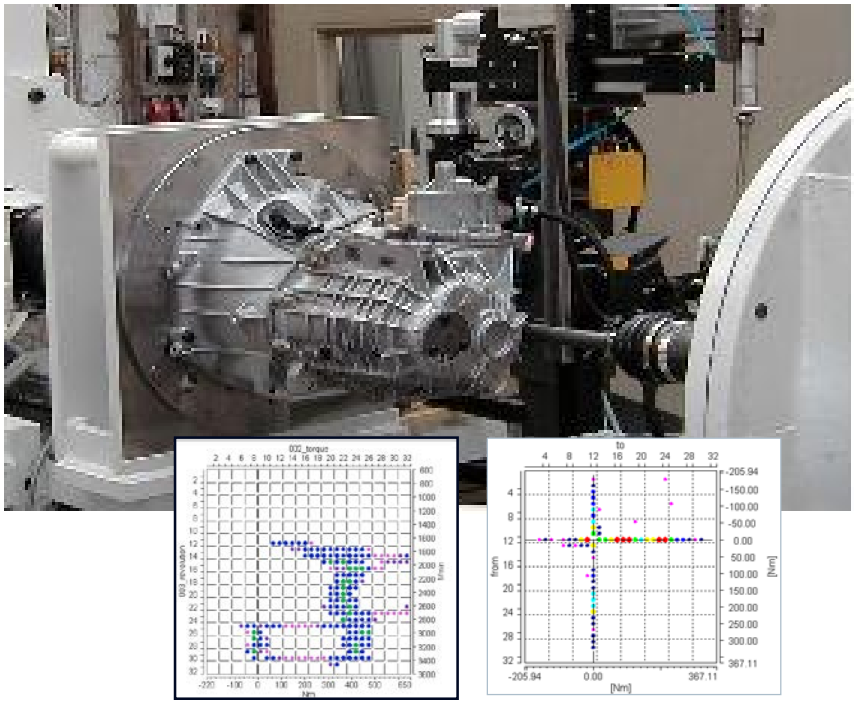
Reference: Ford Gearbox Test Acceleration

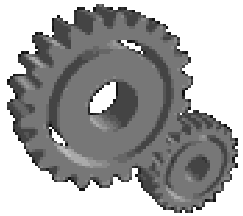


Reduce test duration by 85%

- Reduced testing time
- Customer correlated
- No loose of fatigue content
- Dedicated data reduction methods
- Process integration

Load data reduction for rotating components

- Multi-axial time at level
- Rotating moment histogram
- Rotating rainflow counting



Using LMS advanced load data analysis technologies we were able to improve durability testing procedures for gearboxes and transmission system drastically. Certain subsystem tests could be shortened from previously several weeks to now less than one day."

Dr. Wolfram Weiß, Powertrain development, Ford Köln

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TecWare – RP Filter

How can you accelerate a test ?

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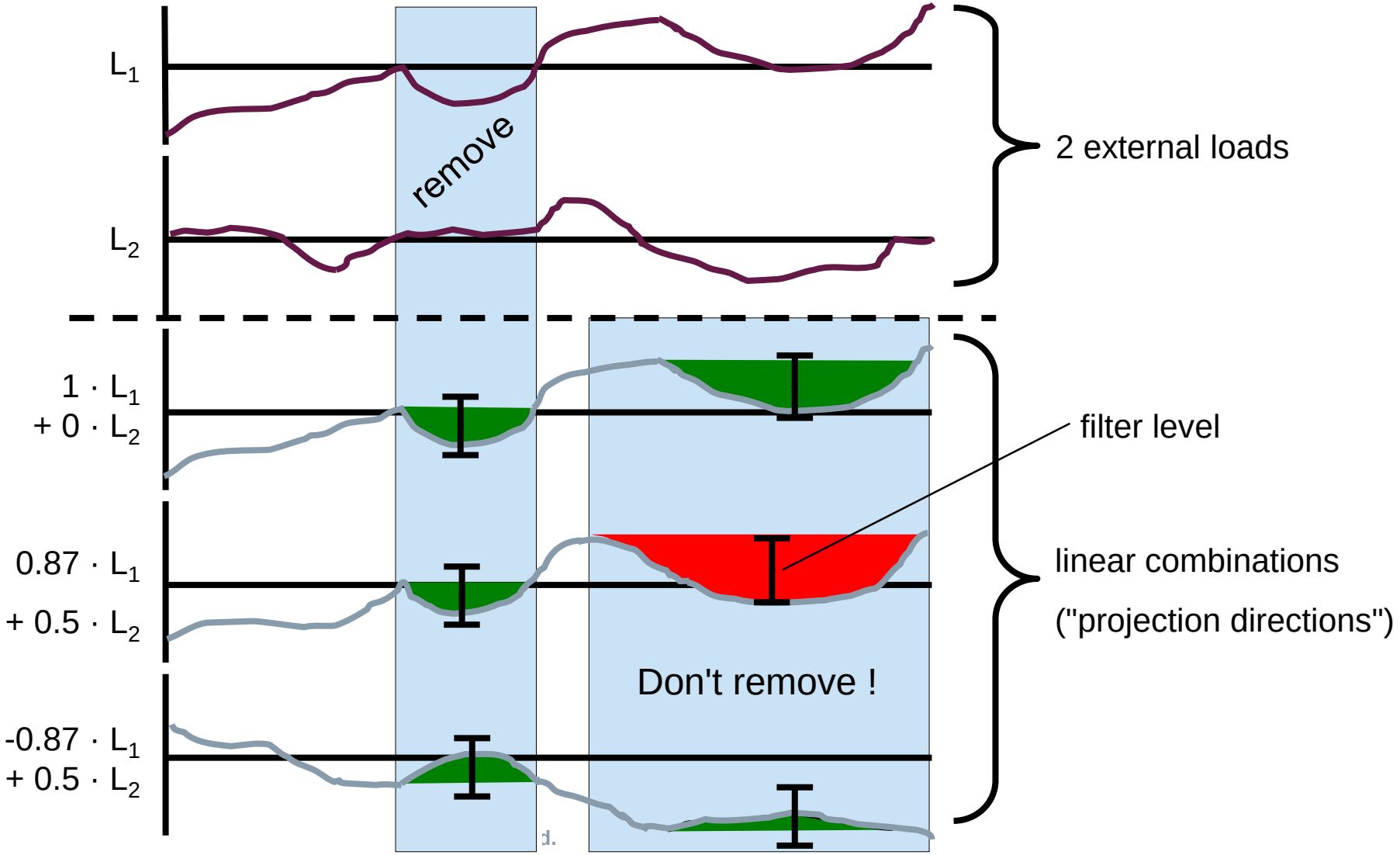
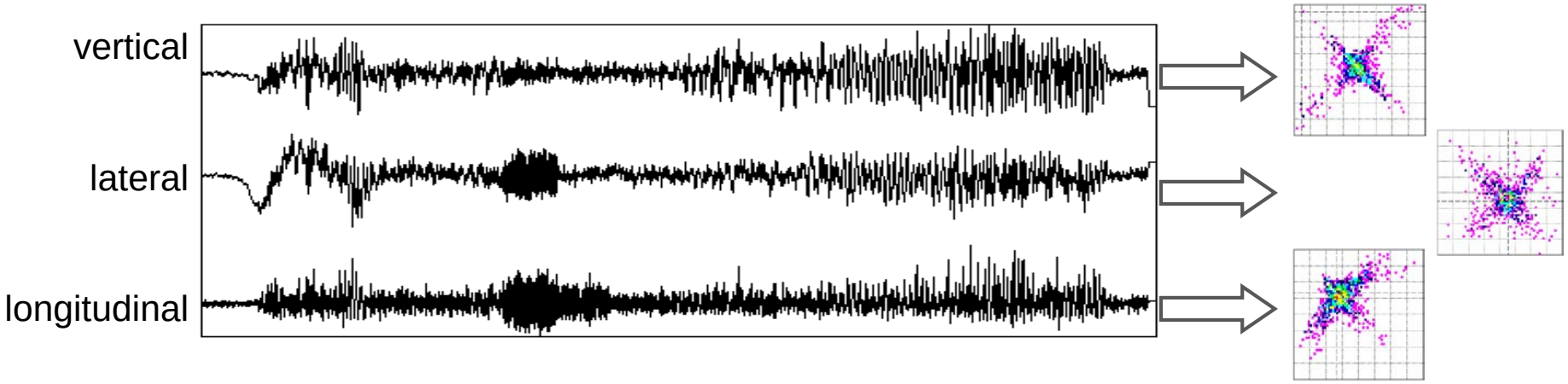
RP-Filter (2D Example)

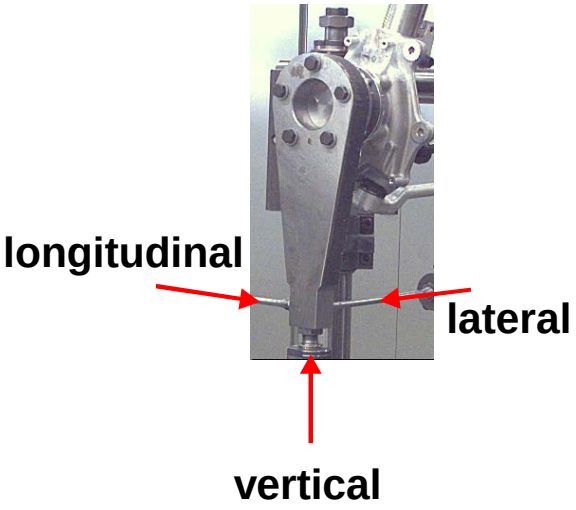


Multiaxial Rainflow – Why?



Uniaxial Rainflow not sufficient

⇨ Phase relation lost



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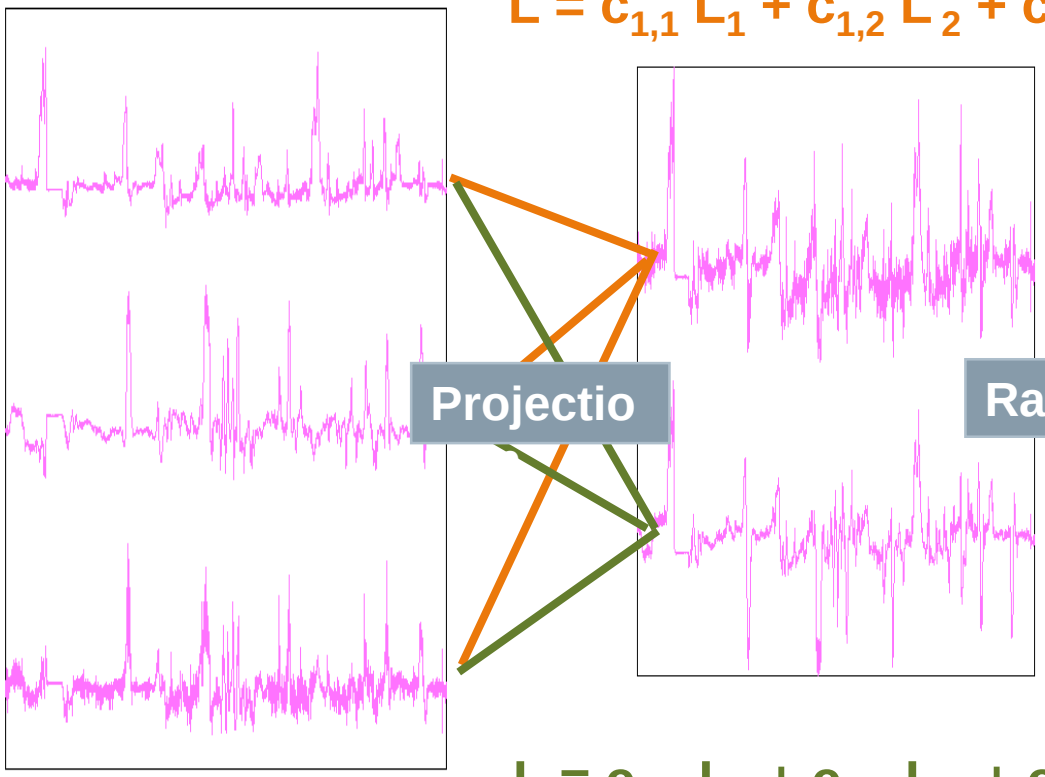
Rainflow Projection Counting – Example (3 channels)

Input signals

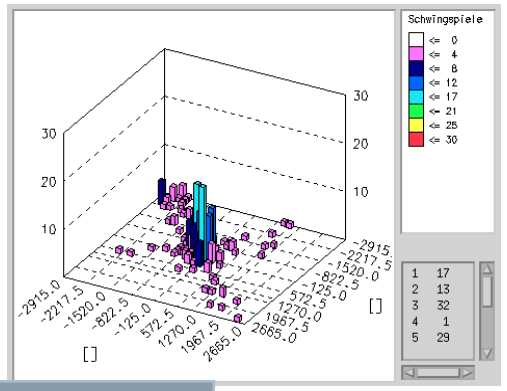
Projected signals

$L = c_{1,1} L_1 + c_{1,2} L_2 + c_{1,3} L_3$

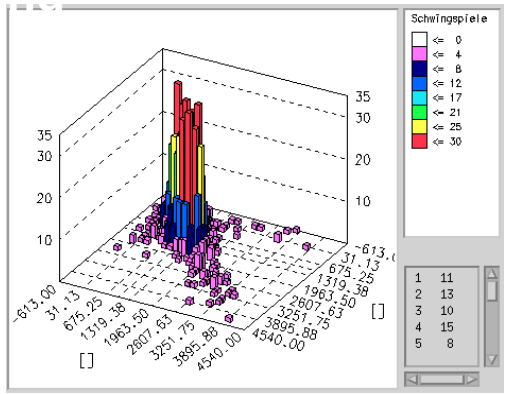


Projectio

Rainflow



$L = c_{2,1} L_1 + c_{2,2} L_2 + c_{2,3} L_3$



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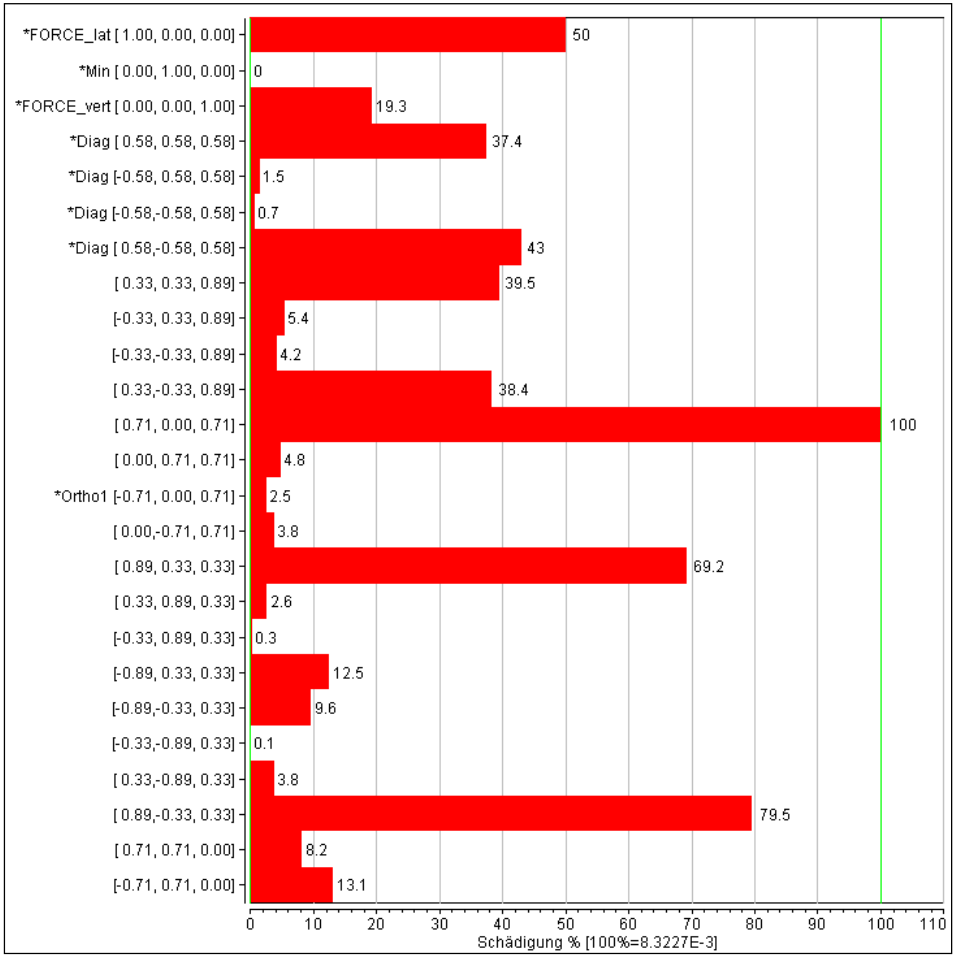
Result Visualization – Multiaxial Rainflow Counting



- "named directions" contain
  - Rainflow matrix and
  - Pseudo damage
- other directions contain only
  - Pseudo damage
- additional counting of individual (user defined) directions
- open display of the load influence plot
  (2- or 3-dimensional)
- display options
  - dorting
  - absolute or relative damage
- swap channels

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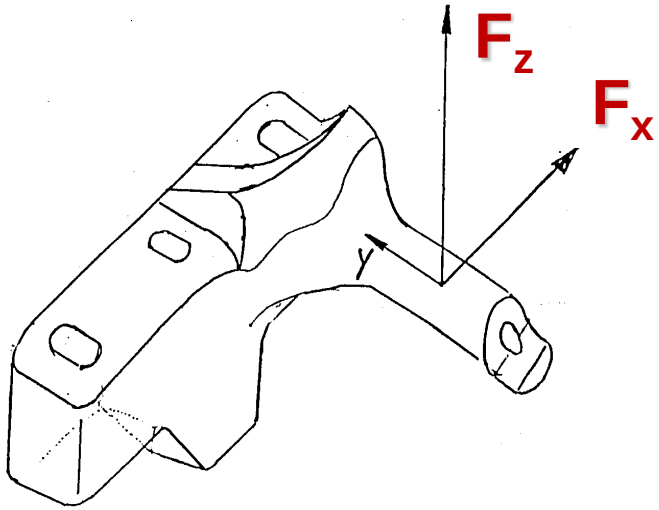
Application Case: VW Engine Mount Console



Accelerating Durability Testing

- Reduced duration of biaxial console testing by LMS RP filtering
- No loose of fatigue content

The application of the LMS TecWare RP filter technique allowed a reduction of the required testing time for an engine mount console to about 20% of the original test time without loosing the fatigue content of the applied test loading.

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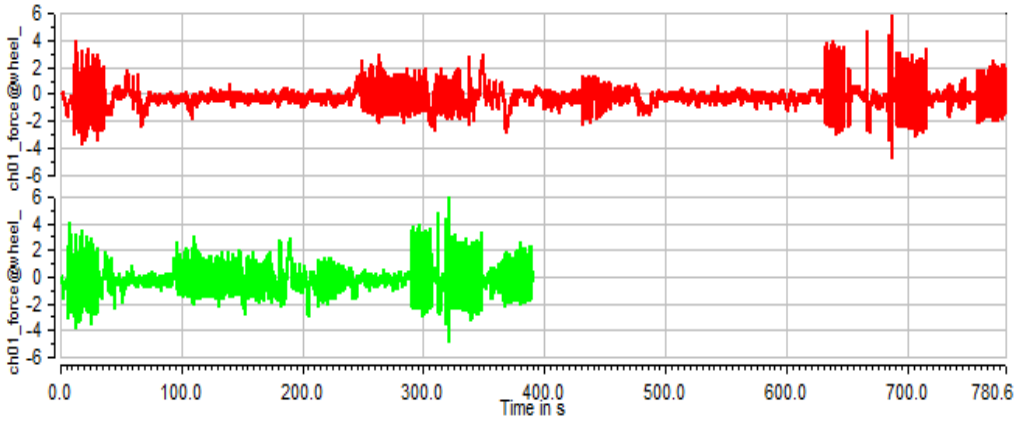
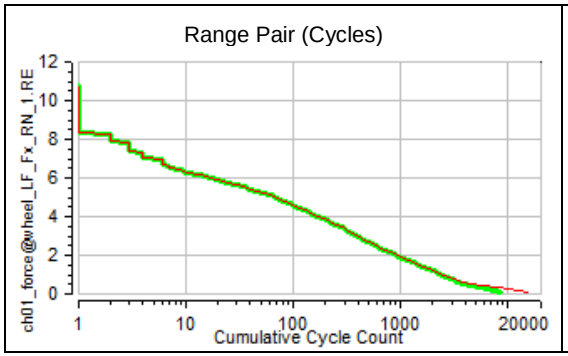
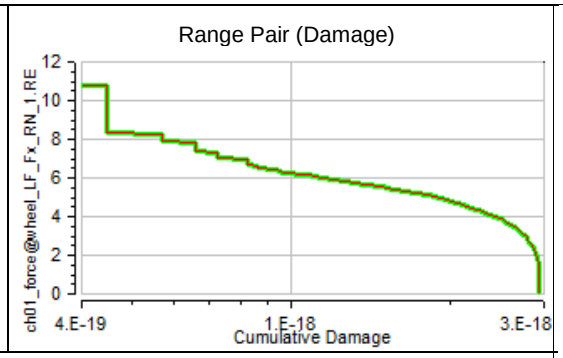
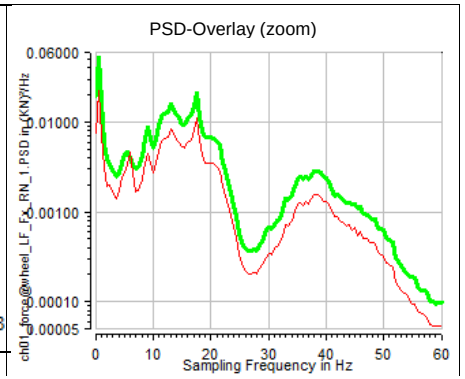
Acceleration of Road Simulator Testing by RP Filtering



	orig.	compressed
Minimum in KN	-4.804	-4.804
Maximum in KN	5.947	5.947
Range in KN	10.751	10.751
Mean in KN	-0.243	-0.227
RMS	0.589	0.689
Std. Dev.	0.537	0.651
Crest-Factor	9.124	7.801
Length in s	780.647	390.277
Max. Gradient KN/s	1141.261	1141.226
Number of bins	100	100
Cycles	15311	8703
Hysteresis filter width	1	1
Residue type	repeated block	
SN curve (k1/k2)	5 / 5	
Pseudo damage	2.95E-18	2.95E-18
Damage ratio	1.00	1.00







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Please do not hesitate to contact me when you need support on durability testing:

- Cell Phone: +86-185-1520-6737
- Email: xudong.li@siemens.com

Your success is the most important thing that we care about !

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Thank you!

Q & A

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SCADAS Satellite

Go distributed and rugged with SCADAS Satellite

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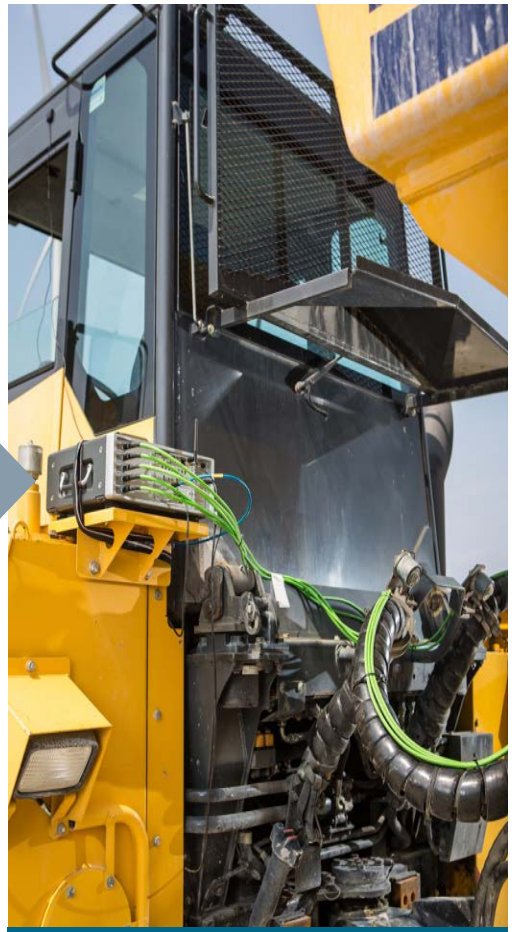
Reduced test campaign costs – 20% savings in instrumentation



Centralized setup increases instrumentation costs

Distributed setup

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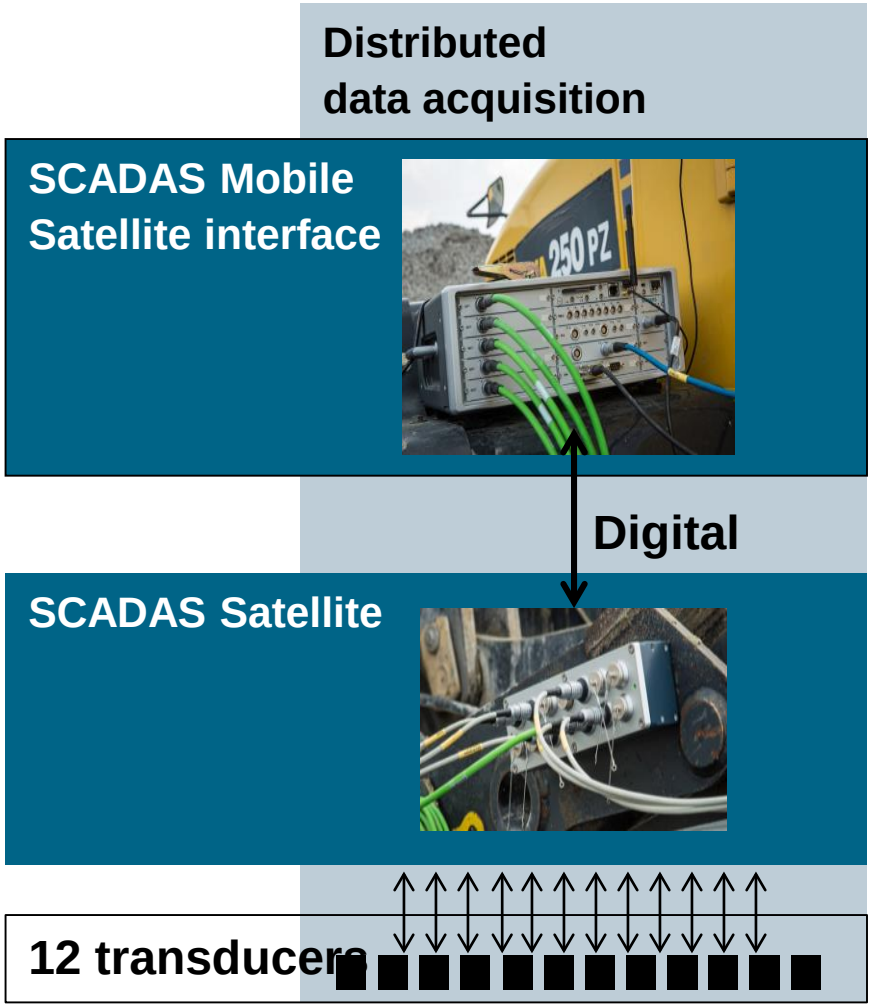
Go distributed and rugged with SCADAS Satellite



- Each SCADAS Mobile Satellite interface module **powers, controls** and **synchronizes one** SCADAS Satellite
- **Digital data transmission** : noise immune, no accuracy loss
- **Automatic synchronization** of all channels into a single file : no risk for errors, time saver
- **Centralized power** distributed to satellites
- **Easy install** with single cable from SCADAS Satellite to SCADAS Mobile or Recorder (5m,15m,50m)

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Signal digitalization close to sensor – High data quality

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ong cables compromise signal accura

Digitalization close to the sensor

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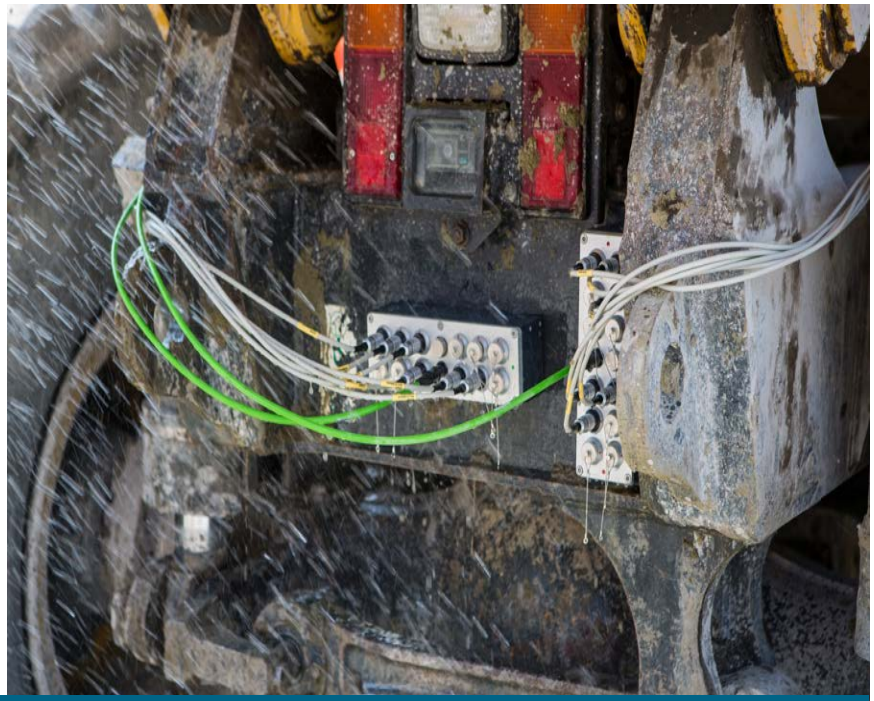
Validating the extremes - 100% certified



signed to confidently execute your test campaigns in the toughest environme

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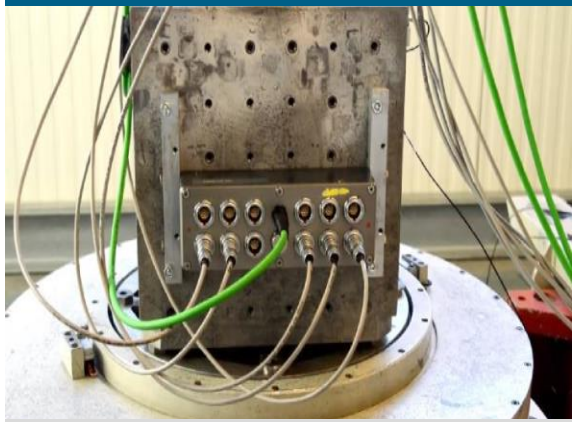
Product overview - LMS SCADAS Satellite at a glance

Water and dust

- IEC 60529: IP66 and IP67
- Dust-tight (IP6x)

Shock and vibration



- MIL-STD-810F
- Vibration: 7.7 grms
- Shock: 100g shock

Temperature

- Wide range
- -40 ºC up to 85 ºC
  -40 ºF up to 185 ºF

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SCADAS Satellite

Extreme testing (IPx6) - Jets

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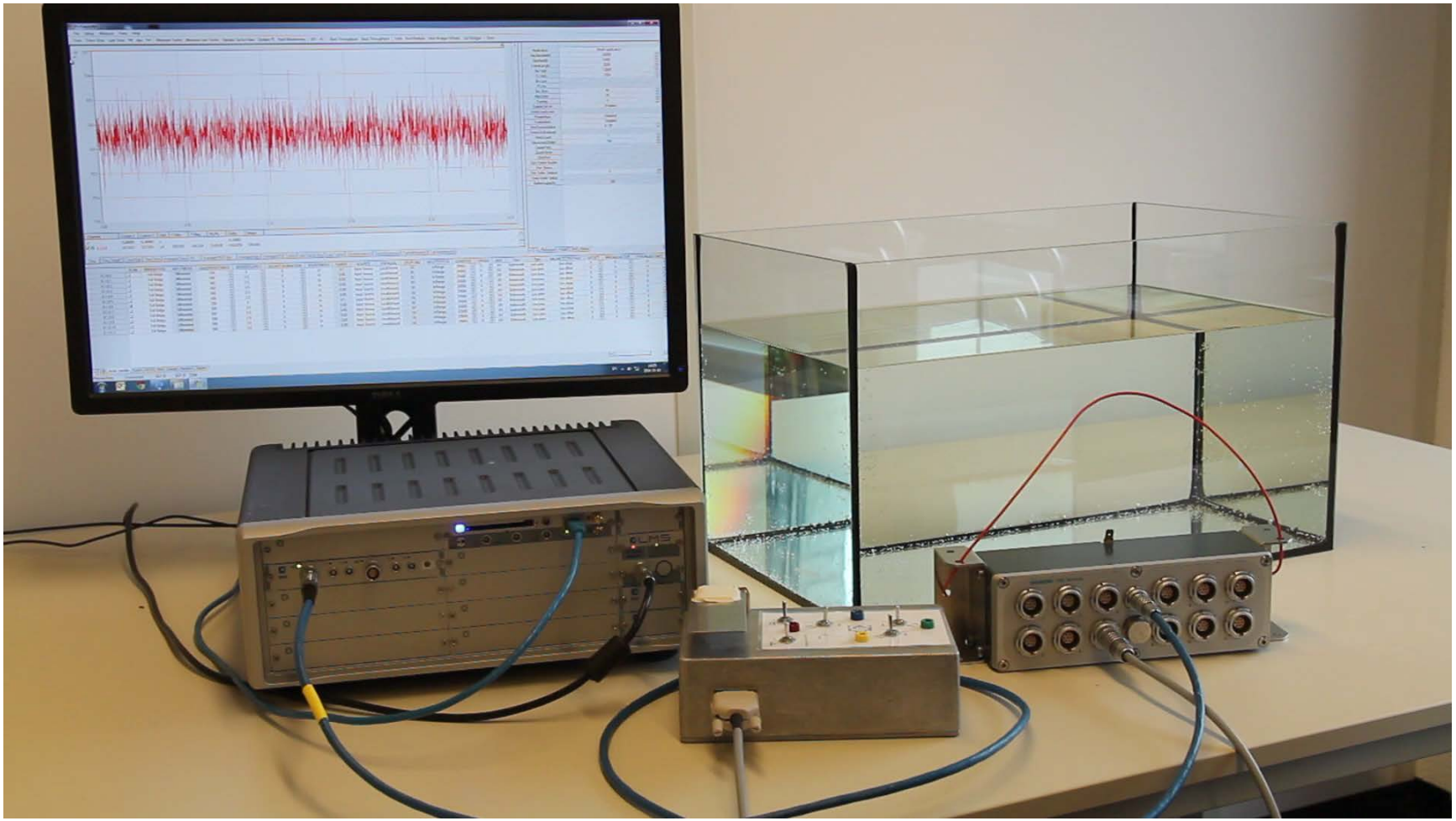
SCADAS Satellite

Extreme testing (IPx7) – Immersion up to 1m



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Go distributed and rugged with SCADAS Satellite
Road load data acquisition for Truck and Bus

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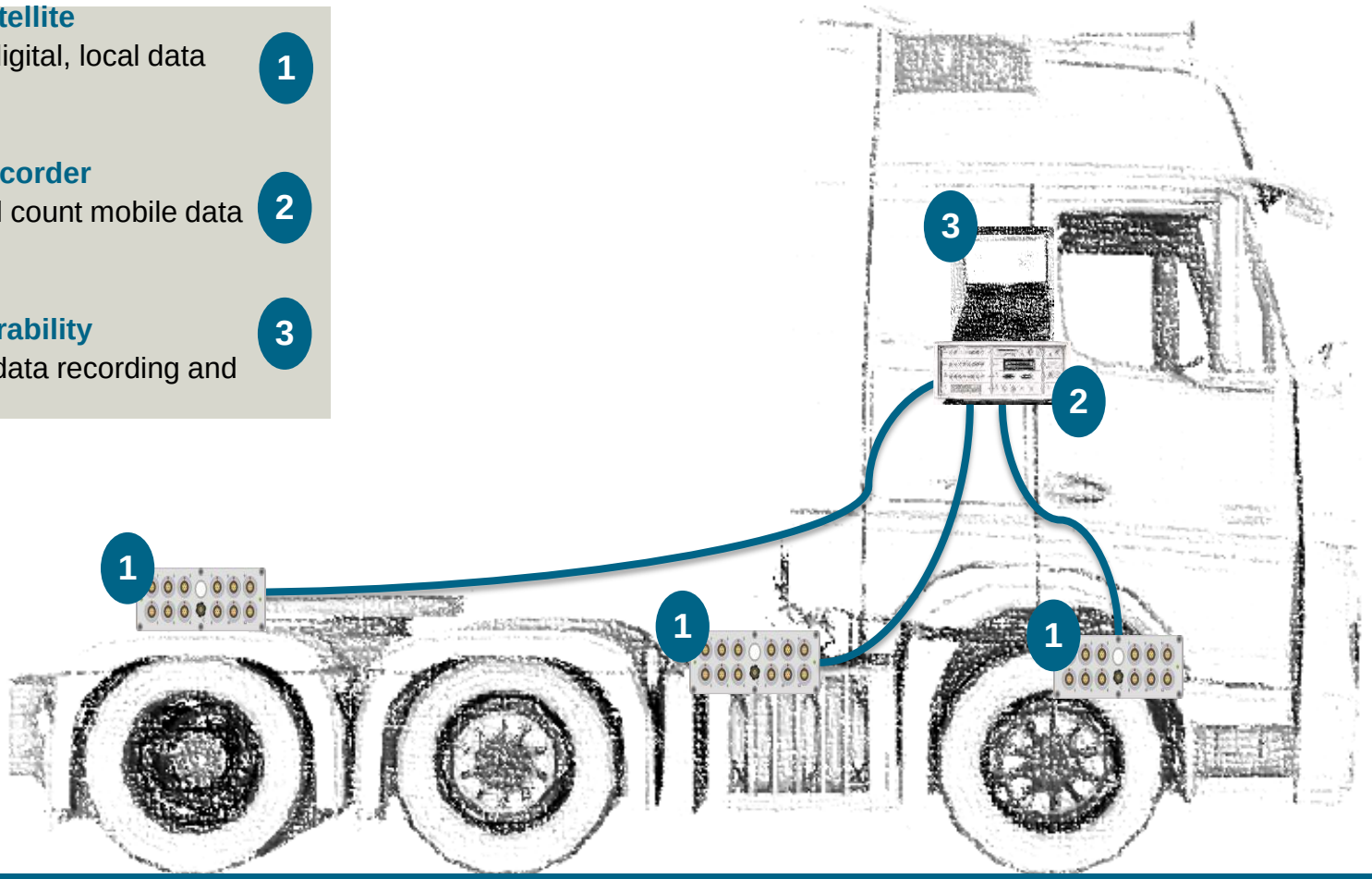
SCADAS Satellite
Distributed, digital, local data acquisition 1

SCADAS Recorder
High-channel count mobile data sync 2

Test.Lab Durability
Quick, easy data recording and validation 3



Typical 200+ channel campaign: strain gages, accelerometers, displacements, wheel force, temperature, CAN, video

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