PROTEST – Procedures for Testing and Measuring Wind Energy Systems
Drive Train Case Study II

Holger Söker, DEWI GmbH

SITE ASSESSMENT . WIND TURBINE ASSESSMENT . GRID INTEGRATION . DUE DILIGENCE . KNOWLEDGE . CONSULTANCY

PROTEST – Background Information

PROcedures for **TEST**ing and measuring wind energy systems

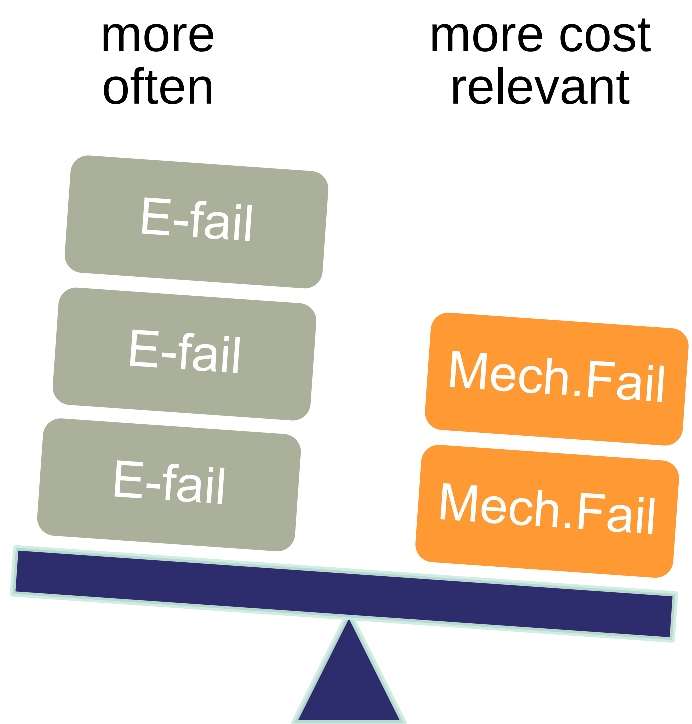
- Collaborative Project in the EU-FP7 BUDGET: 2.7 Mio €
- Start: March 2007 End: Sept. 2010
- Participants:

  ECN (NL) – project co-ordinator,
  Suzlon Energy GmbH (DE),
  DEWI (DE),
  Germanischer Lloyd (DE),
  Hansen Transmissions International (BE),
  University of Stuttgart (DE),
  CRES (GR)

PROTEST – Motivation

PROcedures for **TEST**ing and measuring wind energy systems

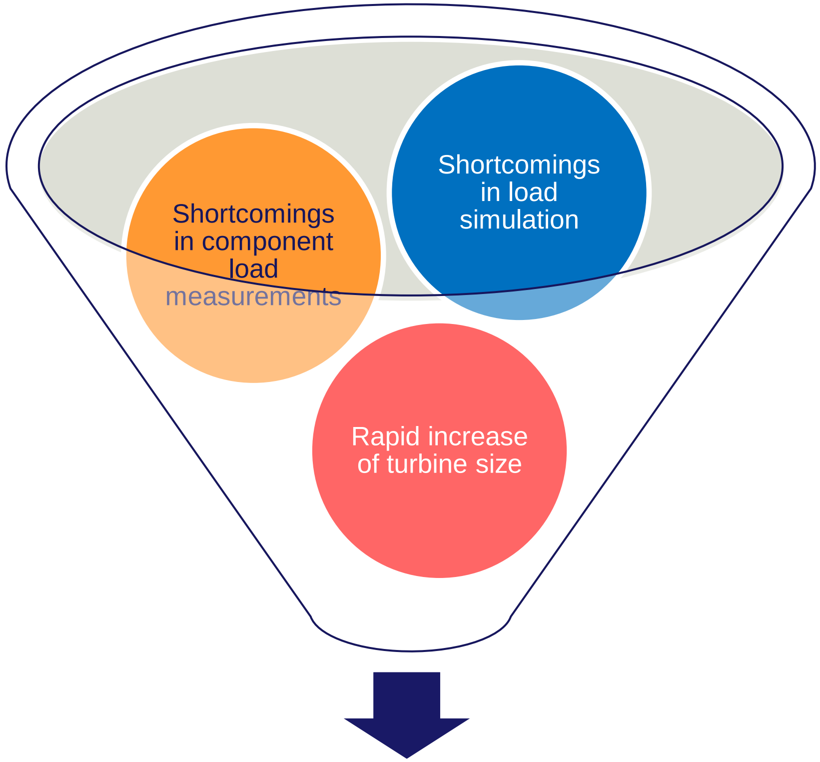
- Focus on mechanical systems:
  fail not very often but O&M cost dominated by repair of failed mechanical systems like



PROcedures for **TEST**ing and measuring wind energy systems

While design procedures for blades and towers are detailed

Such for other mechancial components are rather vague



Potential risk of component failure

PROTEST – Approach

PROcedures for **TEST**ing and measuring wind energy systems

WP 1 State Of Art Report

WP 2 Load cases and design drivers

WP 3 Loads at interfaces

WP 4 Prototype measurements definition

6-step approach

WP 5 Case Studies

Drive Train

Pitch System

Yaw System

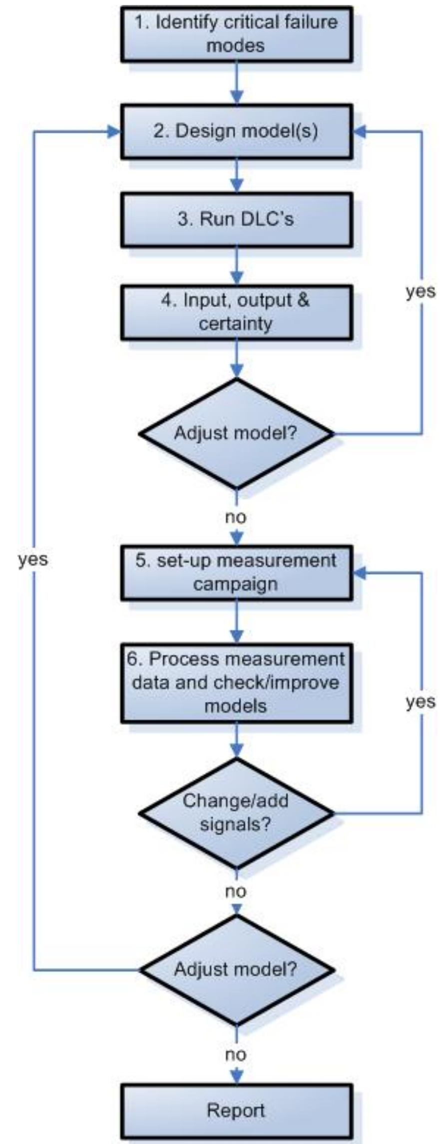
PROTEST – Approach

IEC61400-13 Approach seemed to be not adequate

impossible to define a rigid testing procedure with fixed channels and sampling rates!

6-STEP Approach allows for

- different design and concepts
- different computational models
- allows flexibility to serve the model validation task

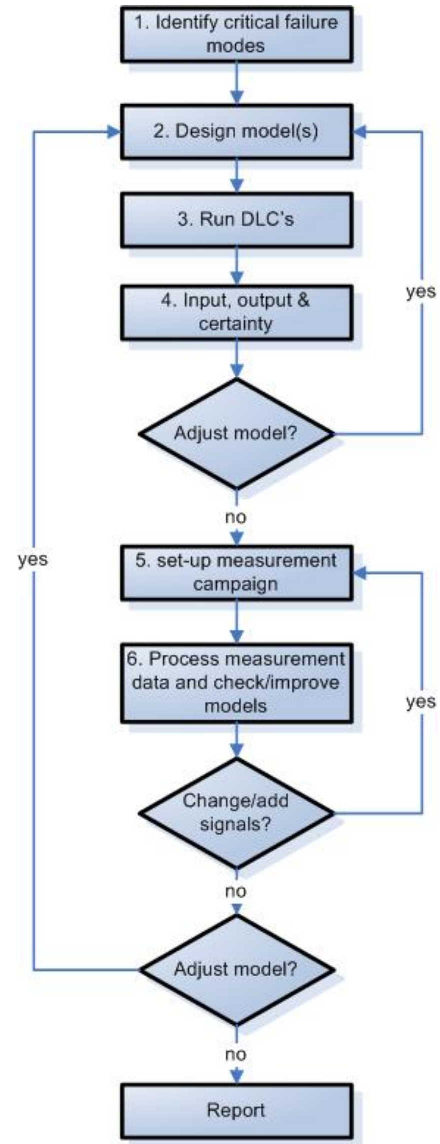


COOPERATION

DEWI Quality by Know-how.

Application of the six-step-approach for validation of a wind turbine drive train

- design & run SIMPACK model
- validate SIMPACK model against validated FLEX5
- sensitivity study of model input parameters
- measurement strategy for model validation
- measurement data processing and analysis
- methods to estimate model parameters from measurements
- comparison of SIMPACK model results/measurements

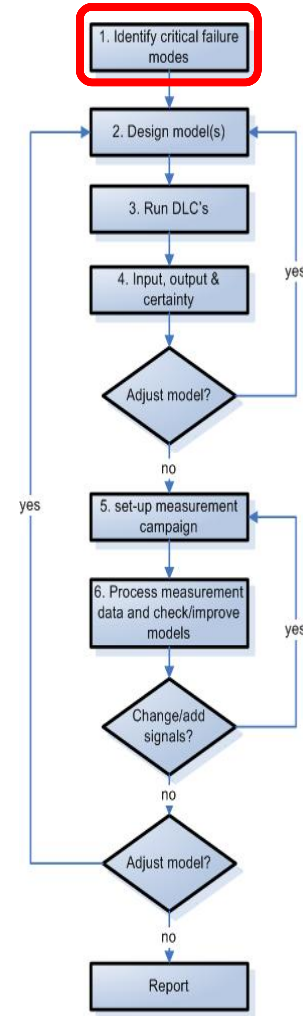


STEP 1: failure modes

No special failure mode was chosen

as the main focus was set on testing

- the process of model design
- measurement set-up
- methods of data processing
- validation of designed models



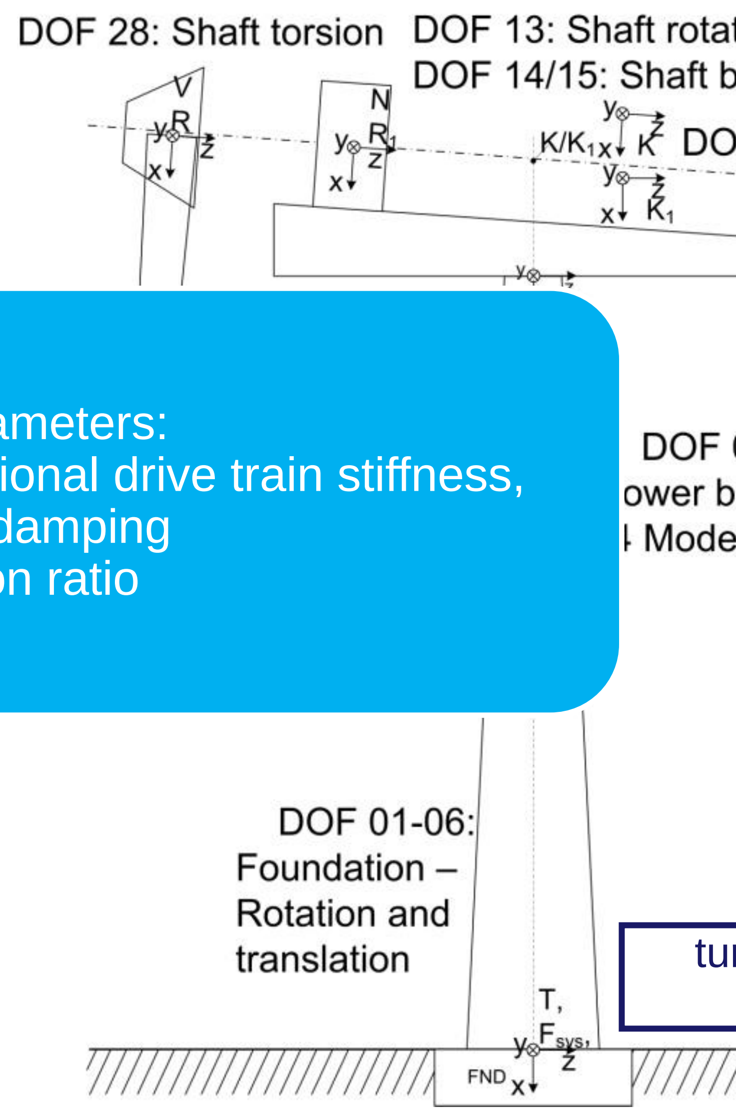
STEP 2: design model

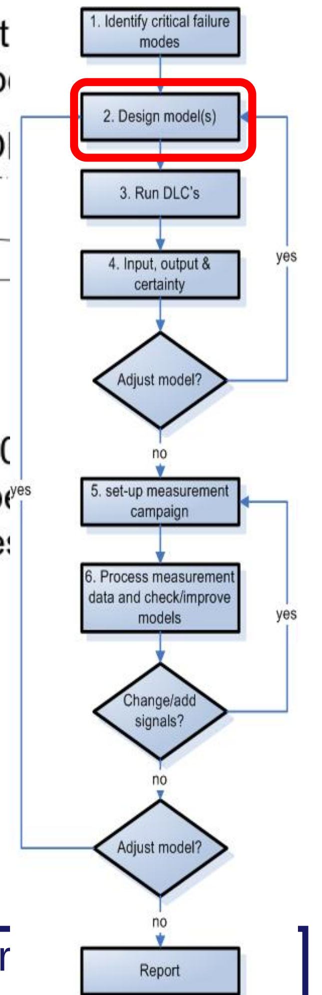
FLEX5 model – 4DOF for Drive Train

- rotation of low speed shaft
- two bending DOFs for main shaft
- torsion between hub and generator rotor

- inertias of rotating parts are one body -individual rotatin considered
- rotation of high speed shaft low speed shaft rotation (sti /gear ratio)

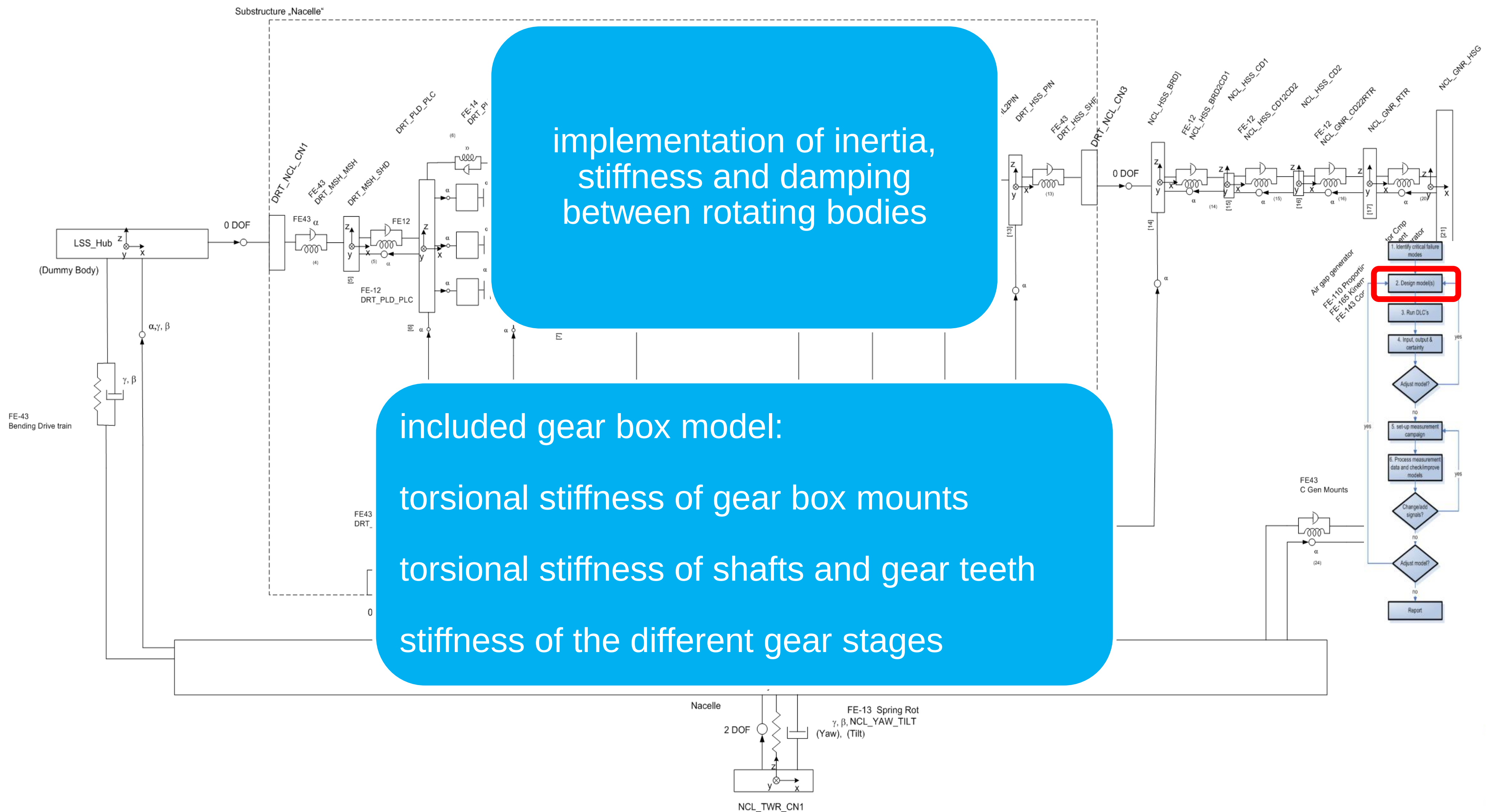
required parameters:
overall torsional drive train stiffness,
drive train damping
transmission ratio





STEP 2: design model

SIMPACK model – stage2 sophisticated model



implementation of inertia, stiffness and damping between rotating bodies

included gear box model:

torsional stiffness of gear box mounts

torsional stiffness of shafts and gear teeth

stiffness of the different gear stages

STEP 4: determine relevant parameter

- Sensitivity Analysis on gives information on the effect of input input parameters uncertainty on simulation results
- starting point for measurement campaign (STEP 5)

- <u>1st approach:</u>

  vary model parameter (e.g. high speed shaft stiffness)

  run a modal analysis

  observe the change of the resulting eigenfrequencies and eigenmodes

  judge what uncertainty is acceptable

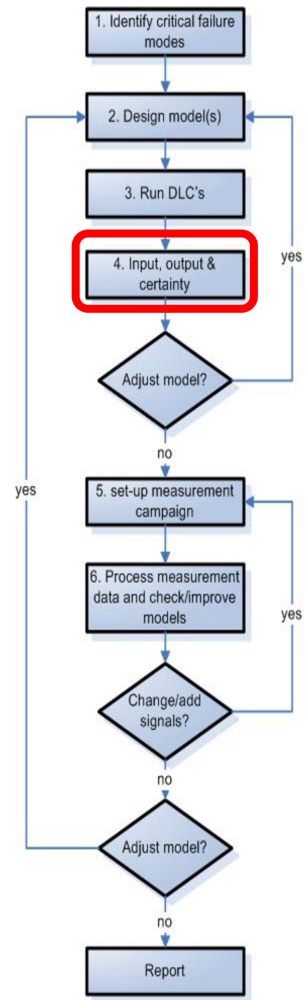
- <u>2nd approach</u>:

  vary model parameter

  run load simulation for relevant DLC's

  analyze results i.t.o. load statistics, Rainflow count

  judge what uncertainty is acceptable.



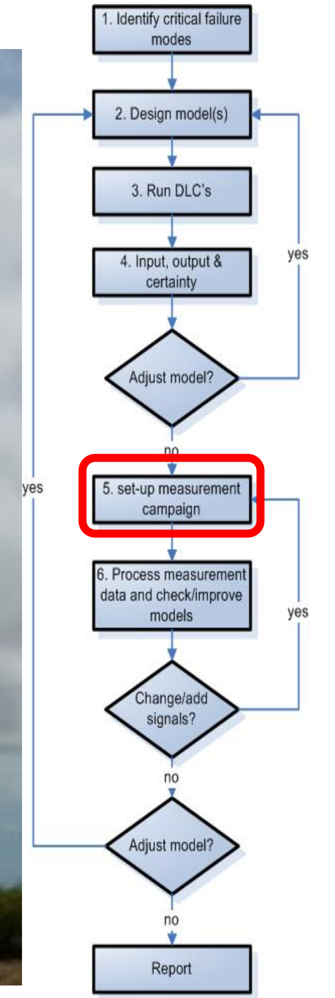
STEP 5: measurement campaign

turbine type :
Suzlon Energy S82 / 1500kW

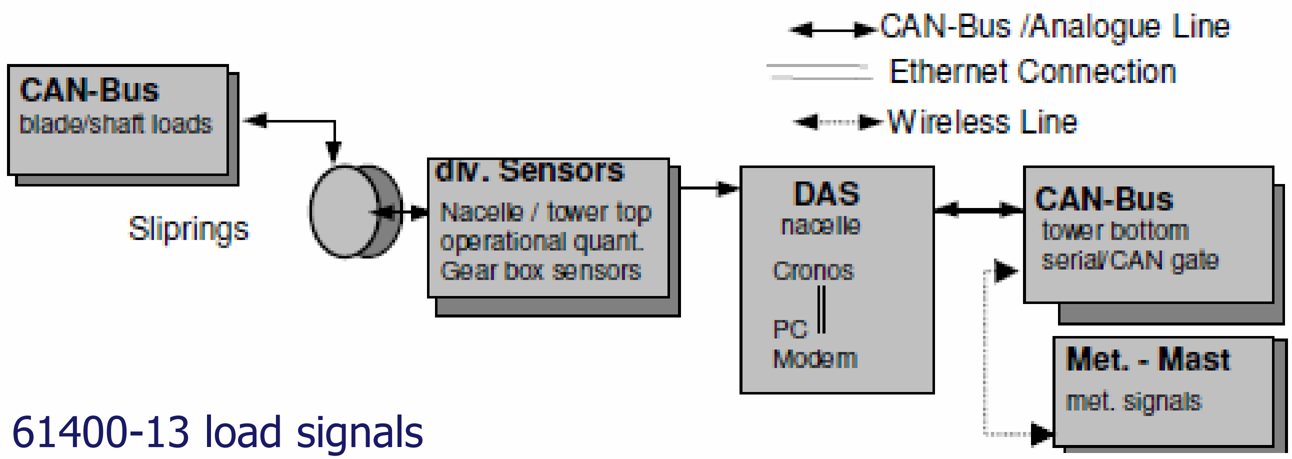
rotor diameter: 82m

gear box:
Hansen, EH751A

site:
Tamil Nadu/India



Measurement setup



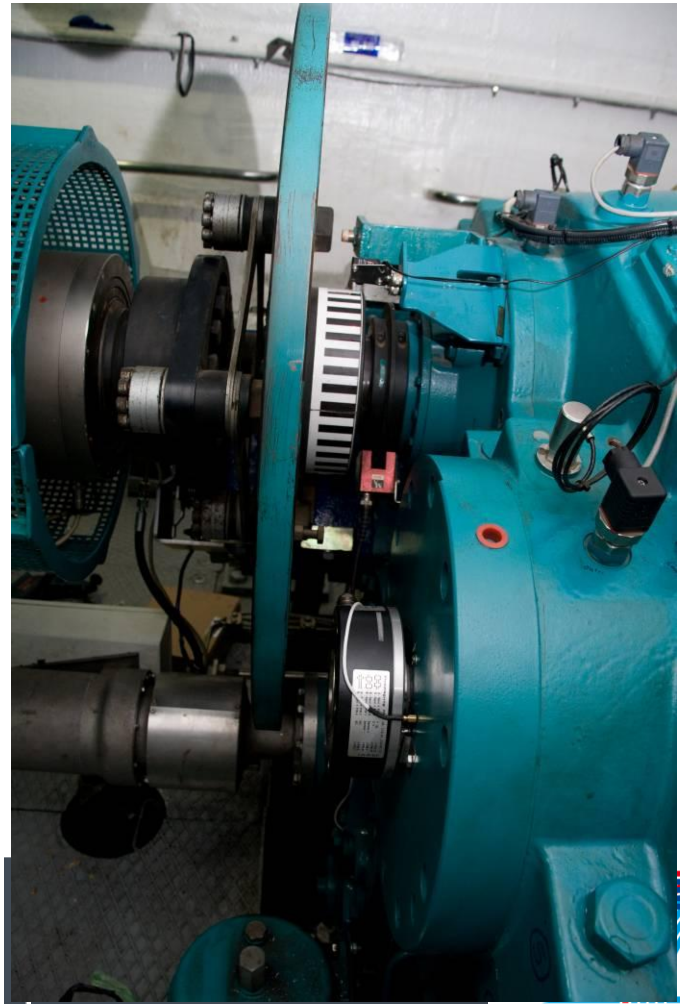
standard IEC 61400-13 load signals

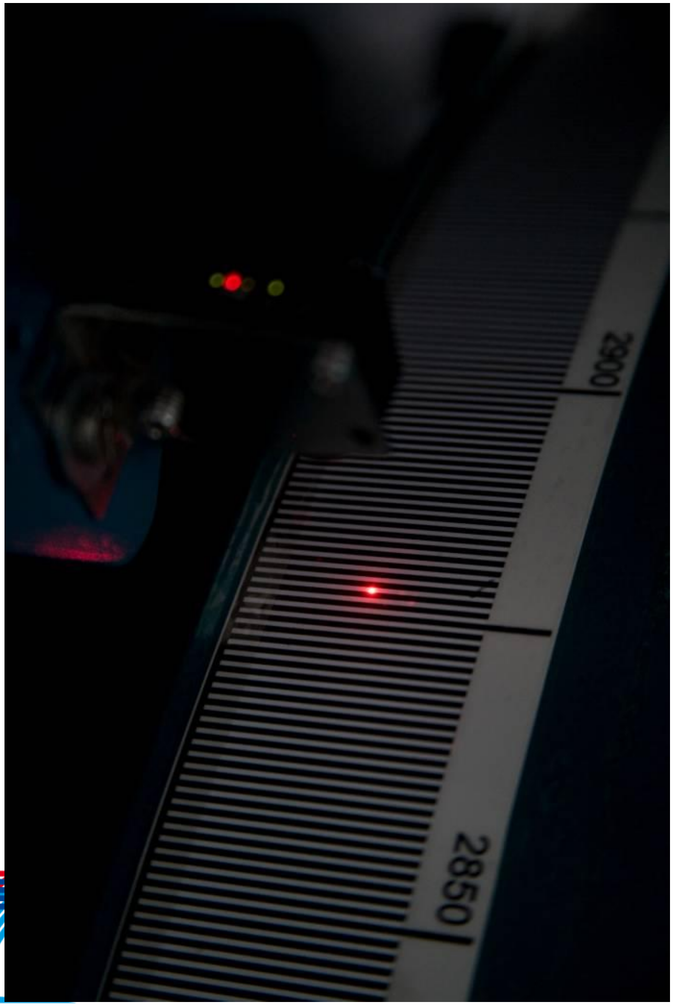
- blade loads (root beding edgewise, flapwise)
- main shaft loads (bending and torque LSS)
- tower top torsion
- tower base bending
- sampling rate 50Hz

for drive train model validation, load validation

- shaft speeds and torques
- displacements of gearbox housing
- temperatures of bearings and oil
- oil pressures

Rotational speed measurements





STEP 5: measurement campaign

Focus on
model validation

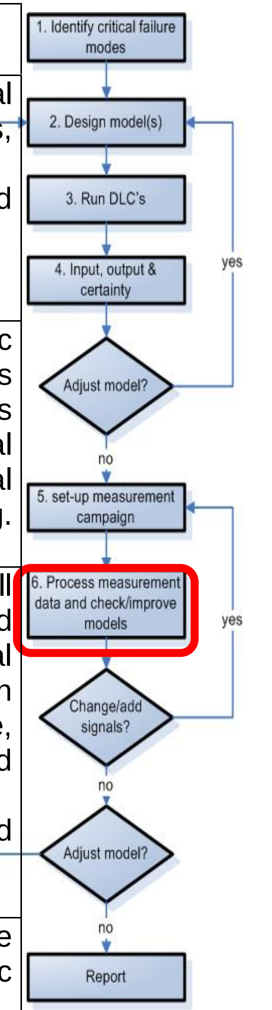
manned measurements to capture specific measurement load cases MLC

December 2008,
June 2010

contiuous monitoring to capture normal power production MLCs

December 2008,
June 2010

Step	Quantity to Check	Example for Methods	Objective of Validation Step
1	▪ Documentation ▪ Selected Time Series	▪ Comparison of model data against weighing log ▪ Spectral analysis of selected time series for various operational states (e.g. in partial and full load)	▪ Main structural properties like masses, stiffnesses, eigenfrequencies and coupled modes
2	Characteristic Curves	▪ Visual comparison of curves of operational parameters (e.g. speed, power) and loading for several environmental conditions	▪ Validation of basic control characteristics and rotor aerodynamics as well as mechanical and electrical parameters (e.g. losses)
3	Time Series of various operational states, like ▪ power production ▪ start ▪ stop ▪ emergency stop	▪ Visual comparison of data in time and frequency domain ▪ Check of statistical properties of data ▪ Analysis of decay rates of oscillations during stopping procedures	▪ Dynamic behaviour all important and assessable operational states with focus on aerodynamic mode, controller model and actuator models ▪ Structural and aerodynamic damping
4	Post-Processed Data	Comparison of loading spectra like ▪ rainflow distribution ▪ load duration distributions ▪ damage equivalent loads	▪ Final check of turbine behaviour and dynamic properties ▪ Check of all previously performed validation steps



COOPERATION

Quality by Know-how.

Normal transients in manual campaign

Run-up

NTH	Constant speed at X RPM - no generator connection = idling (=> X is in the range [100 - 1750 RPM] - generator side)

Special transients in manual campaign

Resonance

STF	Constant speed at Y RPM - power production (=> Y is in the range [1500 - 1600 RPM] - generator side => adapted FLEXISLIP)

Operation at constant power levels

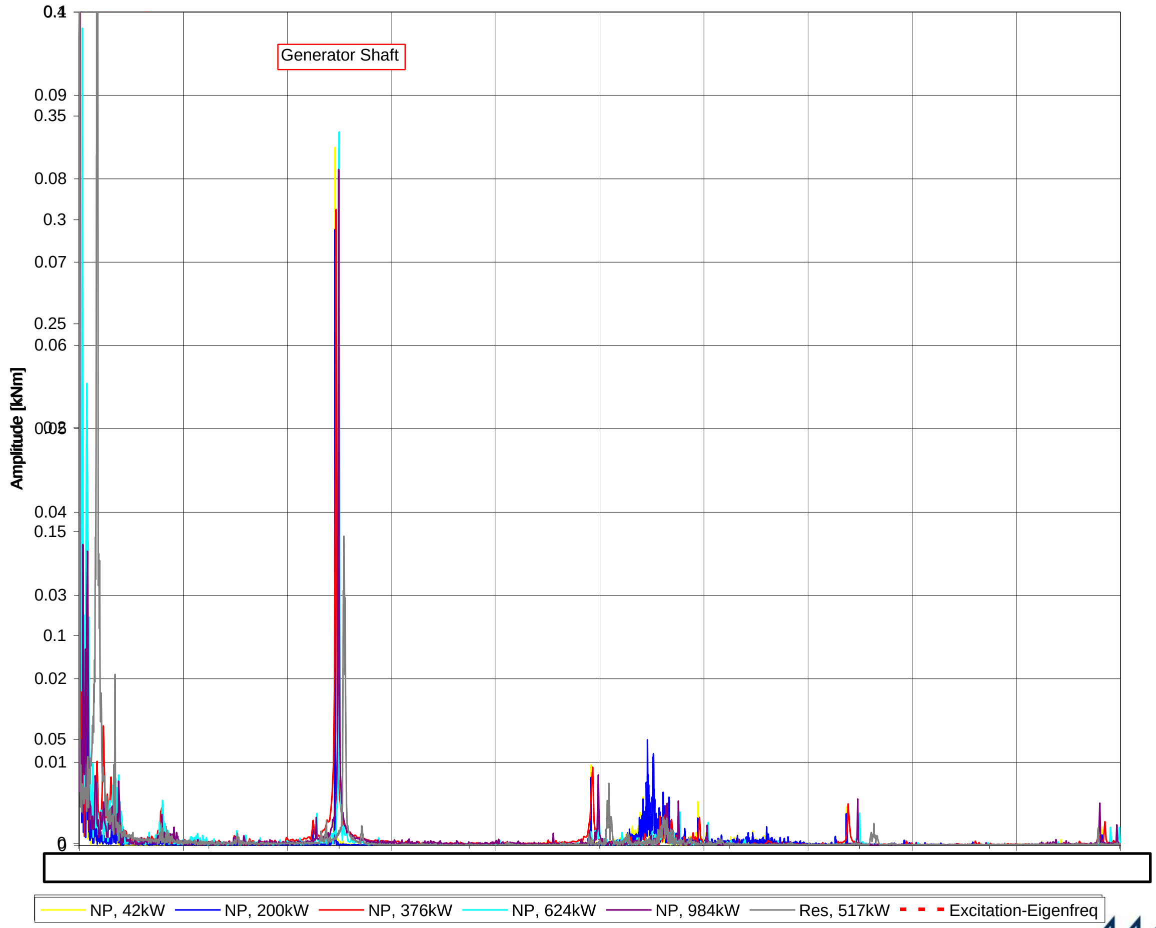
STJ	Constant power production at Z kW (=> Z is in the range [750 - 1500 kW])

STEP 6: data processing

Selected Time Series: Operation at different load levels for Eigenfrequency determination

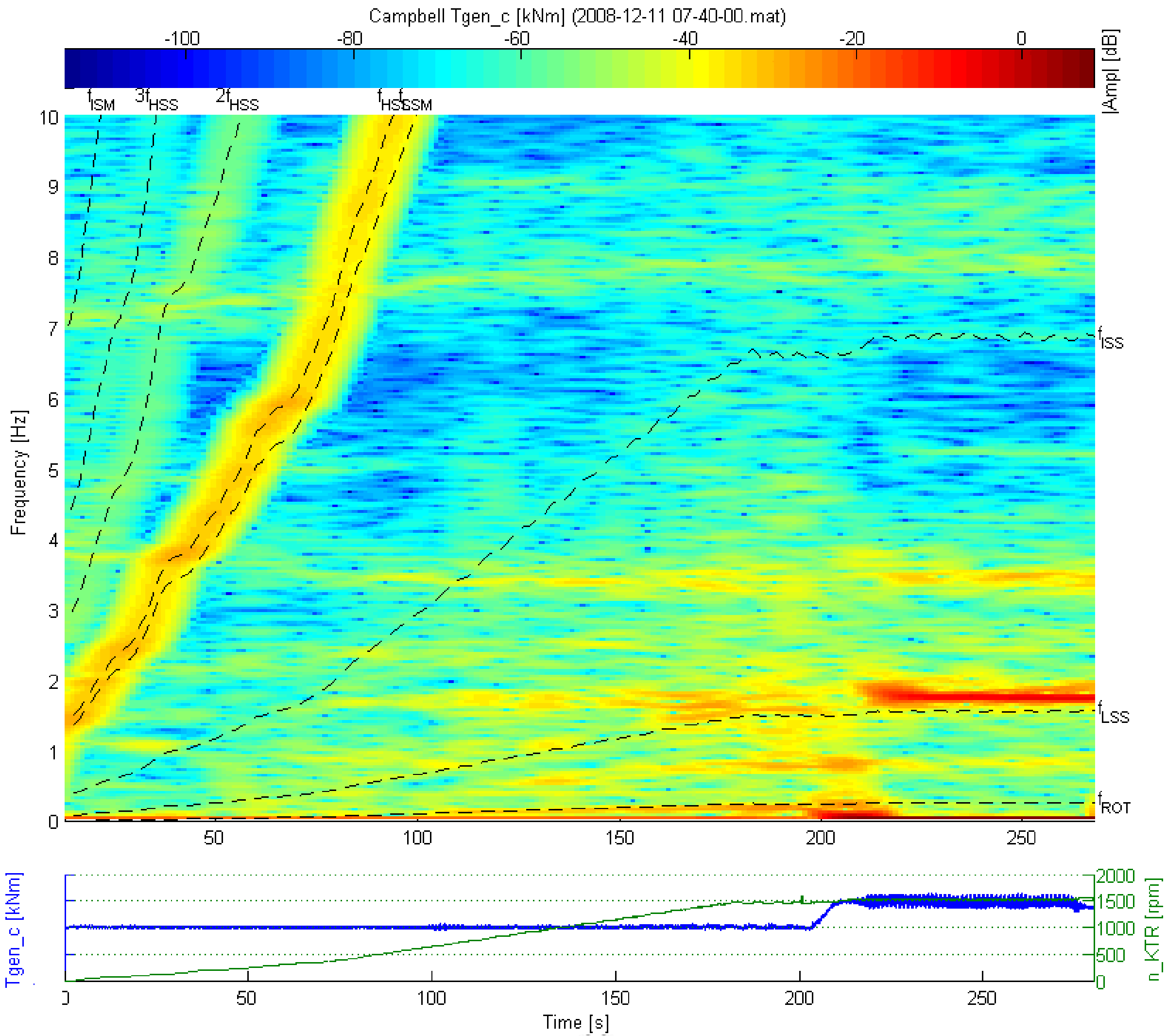
excitation frequencies

	rotational speed [rpm]	exitation fequency [Hz]
generator	1495.2	24.92
rotor 1st order	15.7	0.26
rotor 3rd order	47.1	0.79
rotor 6st order	94.2	1.57



DEWI Quality by Know-how.

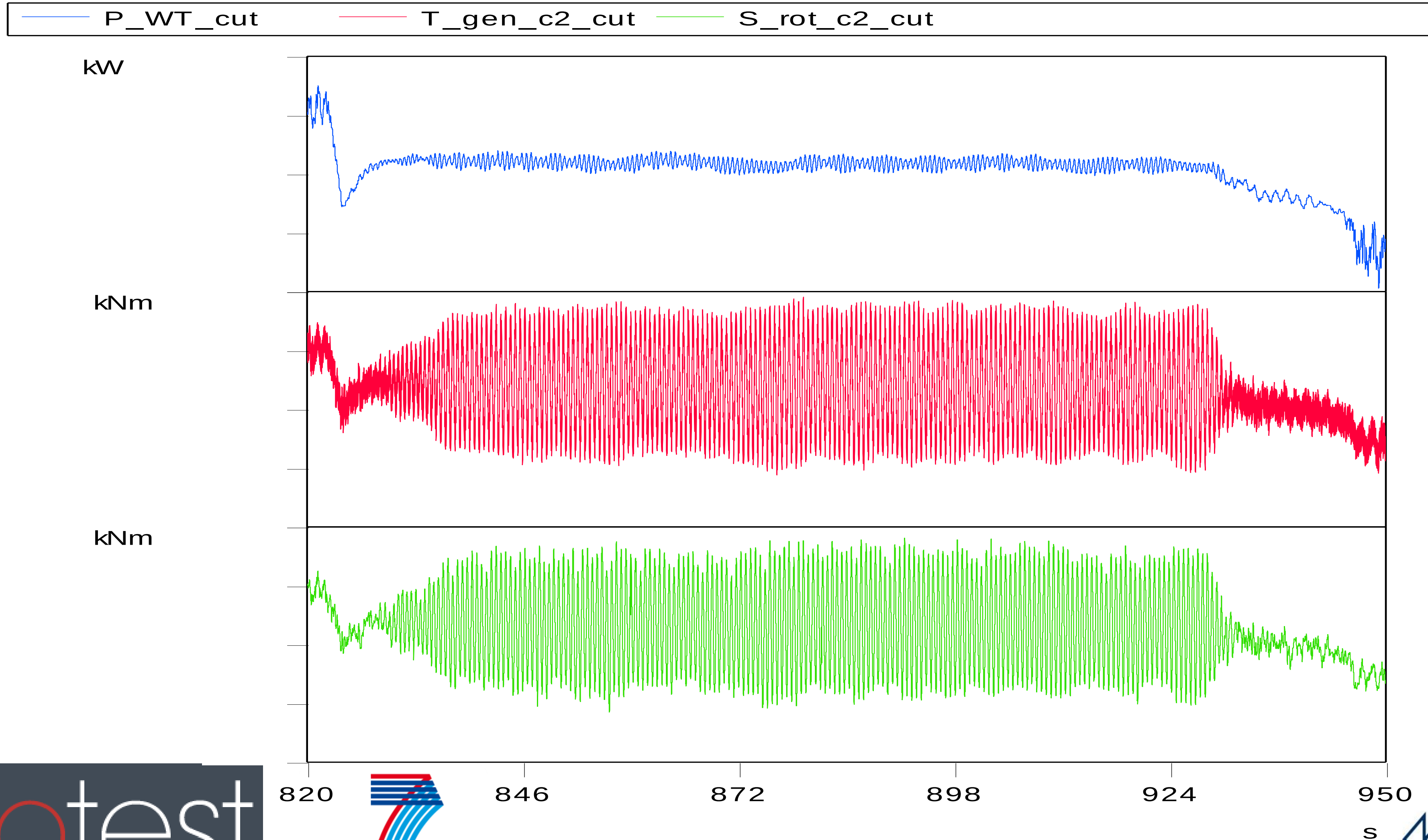
Selected Time Series: Run-up for Eigenfrequency determination



fHSS	: high speed shaft rotating frequency
fISS	: intermediate speed shaft rotating frequency
fLSS	: low speed shaft rotating frequency
fROT	: rotor–main shaft–planet carrier rotating frequency
fHSM	: high speed stage meshing frequency (ISS – HSS)
fISM	: intermediate speed stage meshing frequency (LSS – ISS)
fLSM	: low speed stage meshing frequency (planetary stage)

Quality by Know-how.

Selected Time Series: Deliberate resonance (modified control parameters)

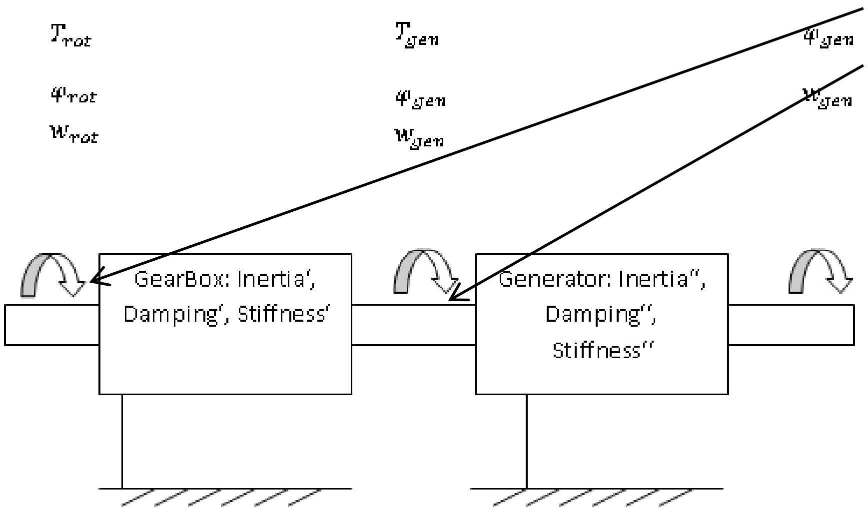


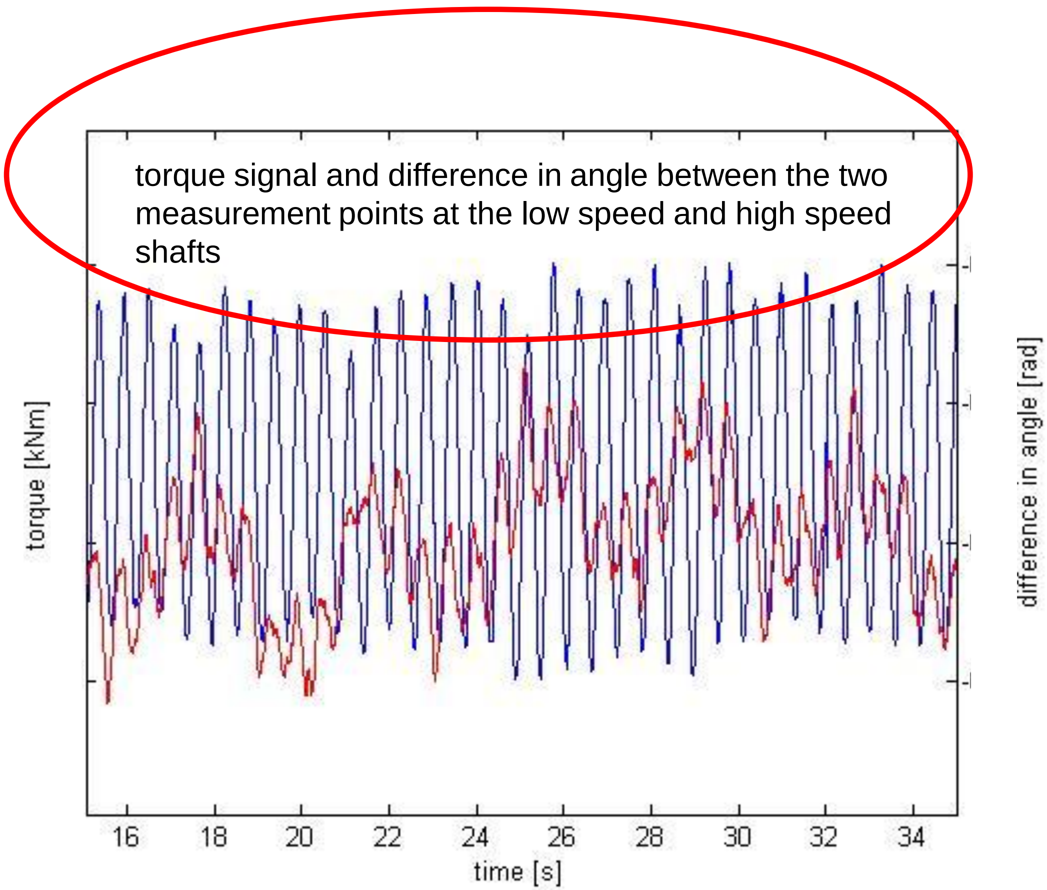
Selected Time Series: Stiffness determination - deterministic approach

analysed data: resonance case

assumption:

$$stiffness = \frac{torque}{angle_{rel}}$$





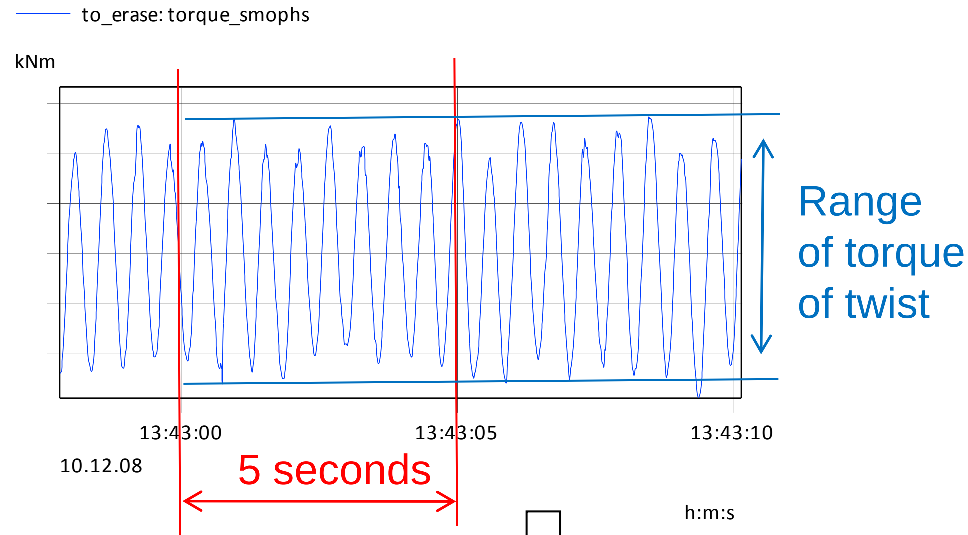
STEP 6: data processing

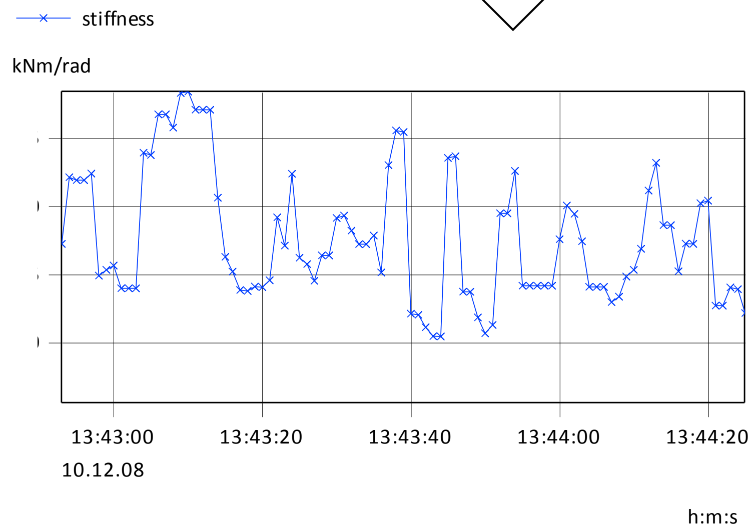
Selected Time Series: Stiffness determination - Stochastic approach

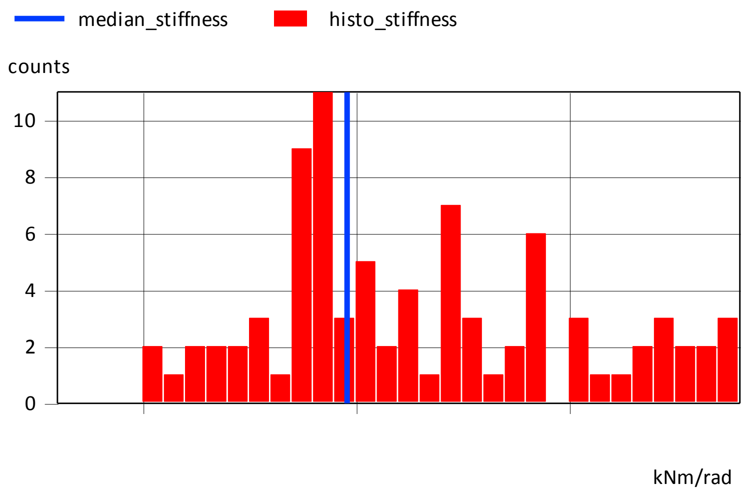
analysed data:stationary resonance

acceleration and damping assumed to be neglectible from one interval n to n+1

$$T_{rotor}\big|_{range} = \left[\varphi_{rotor}\big|_{high} - \varphi_{high}\right]_{range} \cdot Stiffness$$

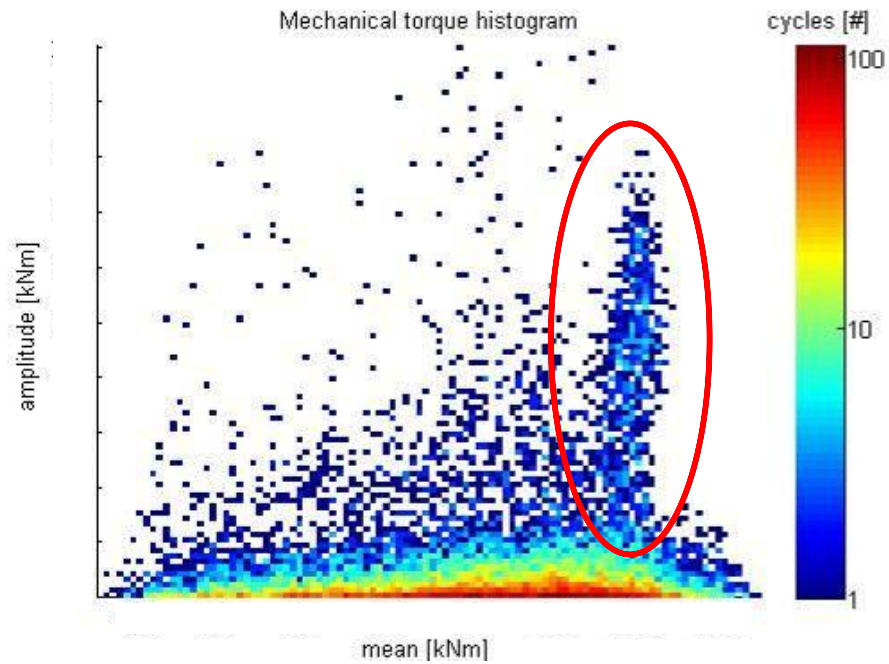






Quality by Know-how.

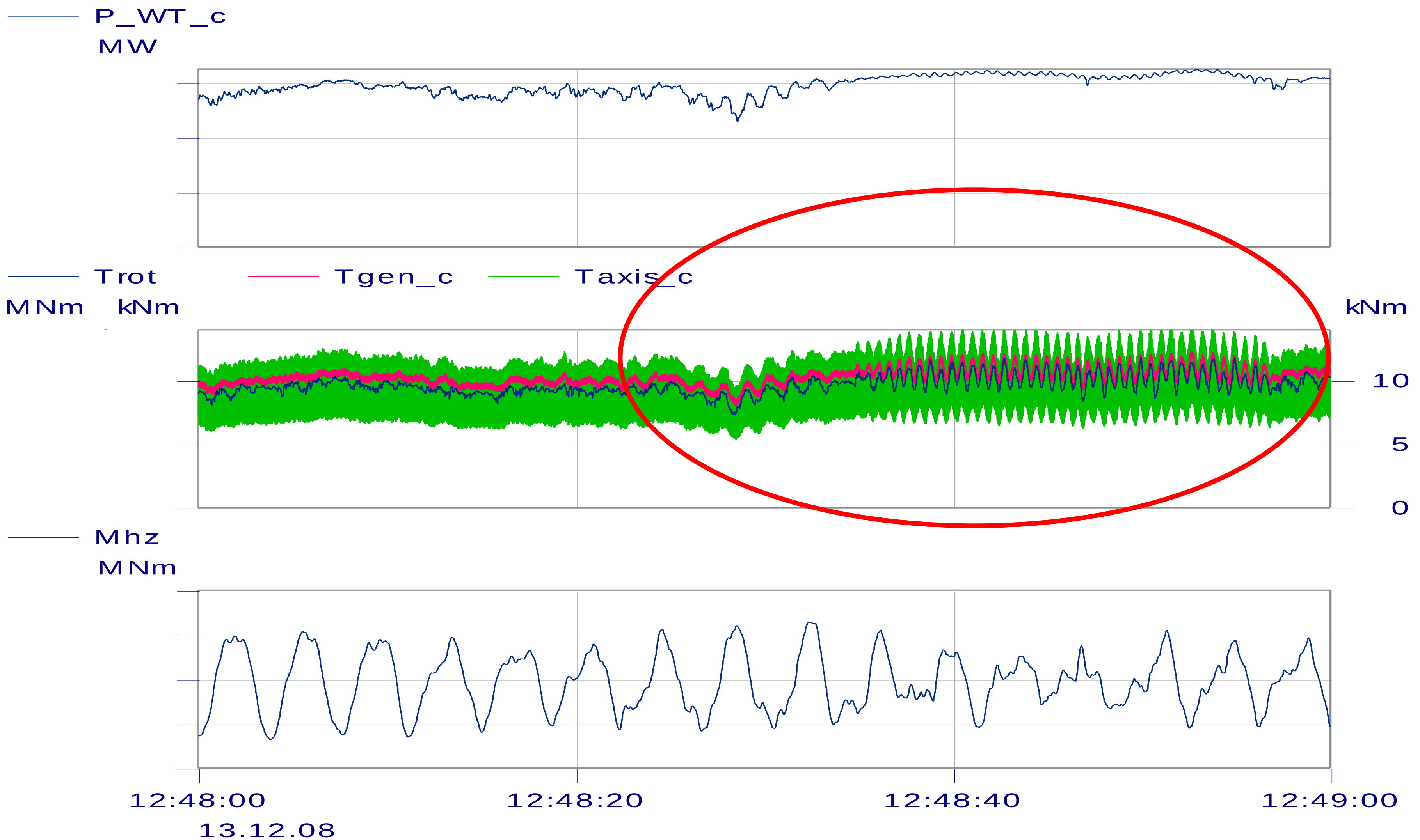
Post- Processed Data: Rainflow Count



RFC's indicate high variations in mechanical torque around rated torque

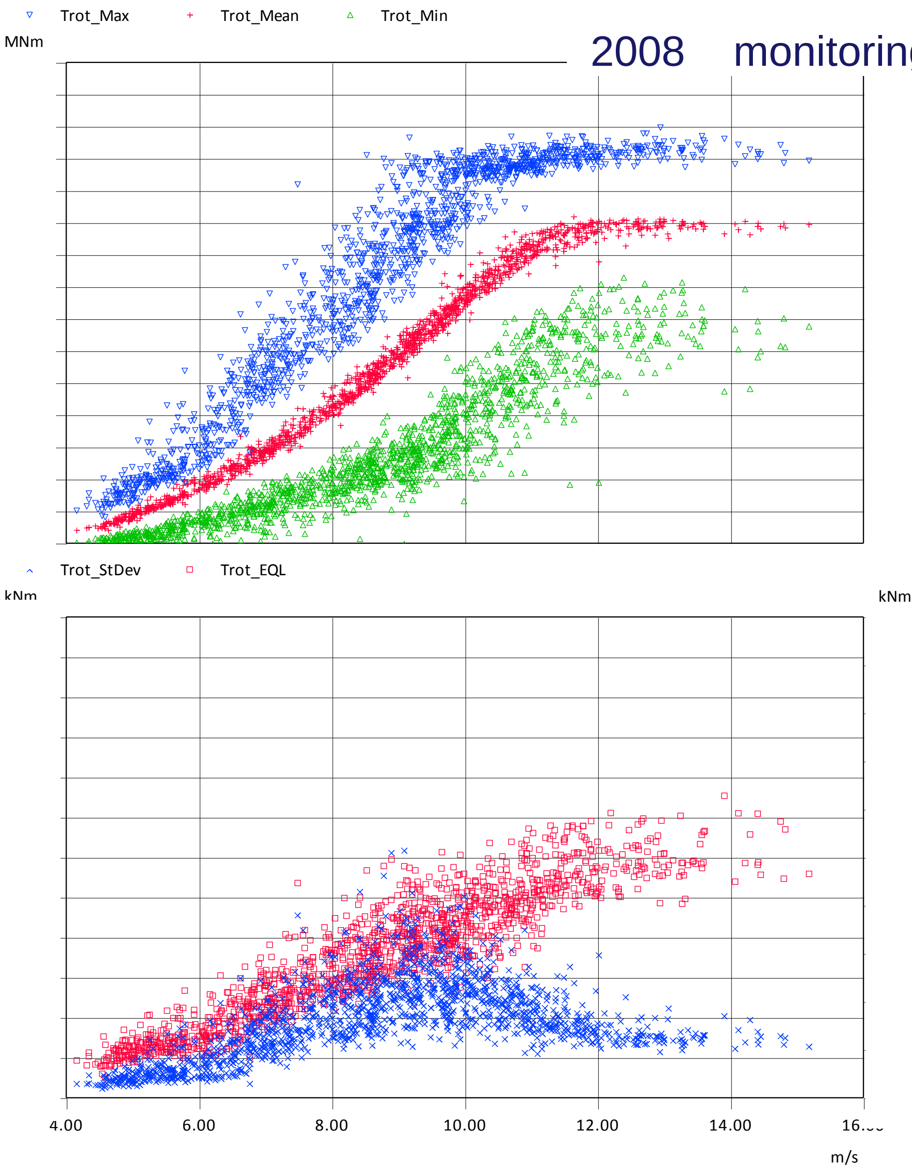
→ further investigation is required to determine (1) the impact and (2) ability of the FLEX5 simulation model to consider this effect

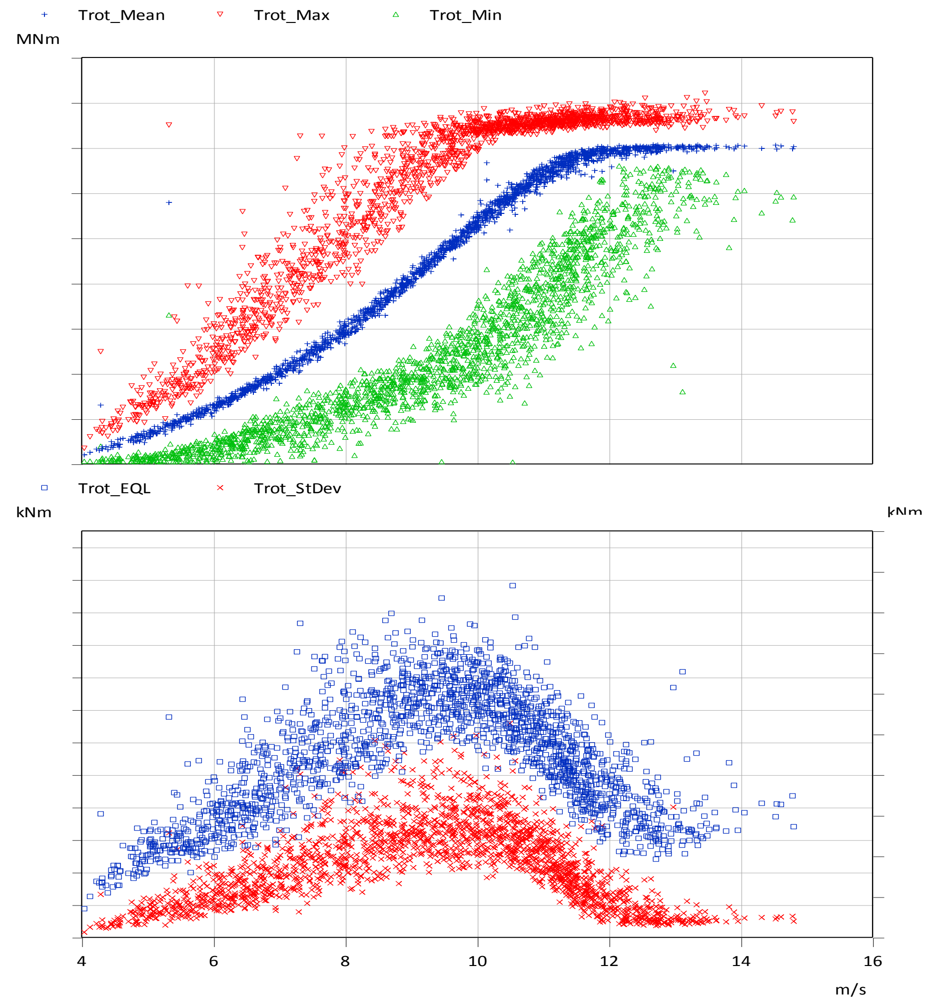
STEP 6: data processing



STEP 6: data processing

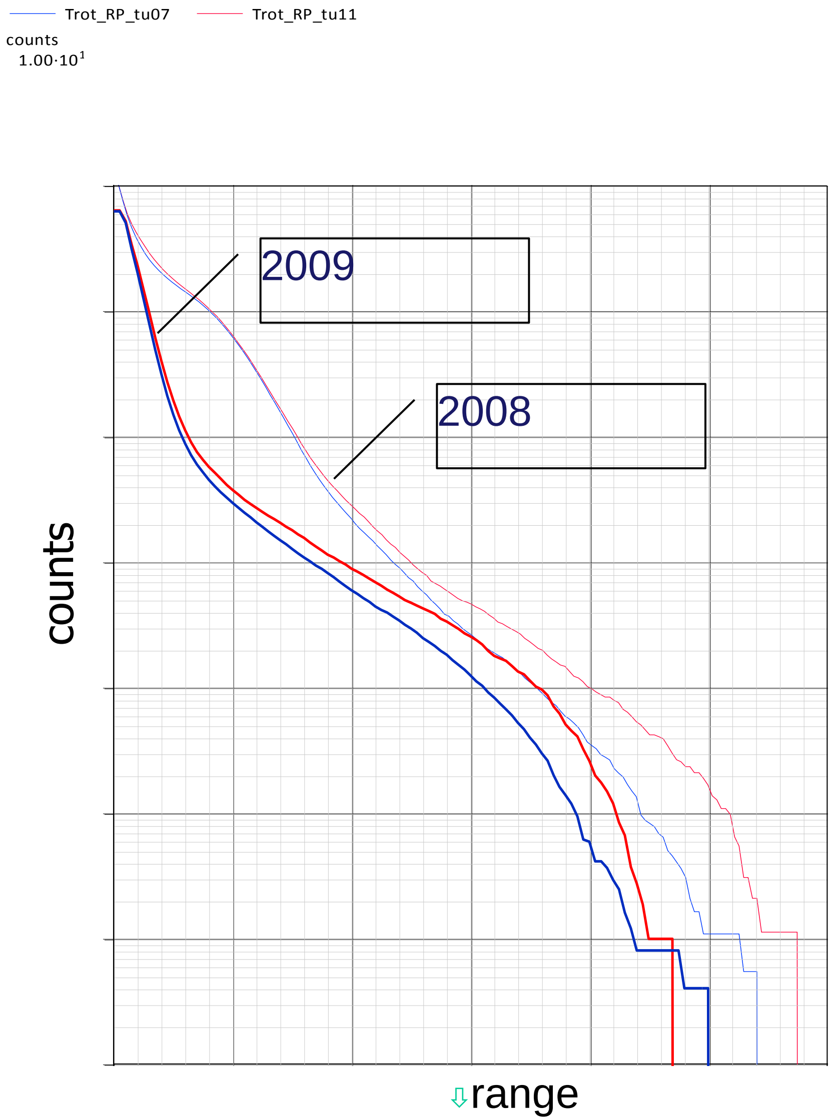
2008 monitoring statistics 2009





Quality by Know-how.

STEP 6: data processing



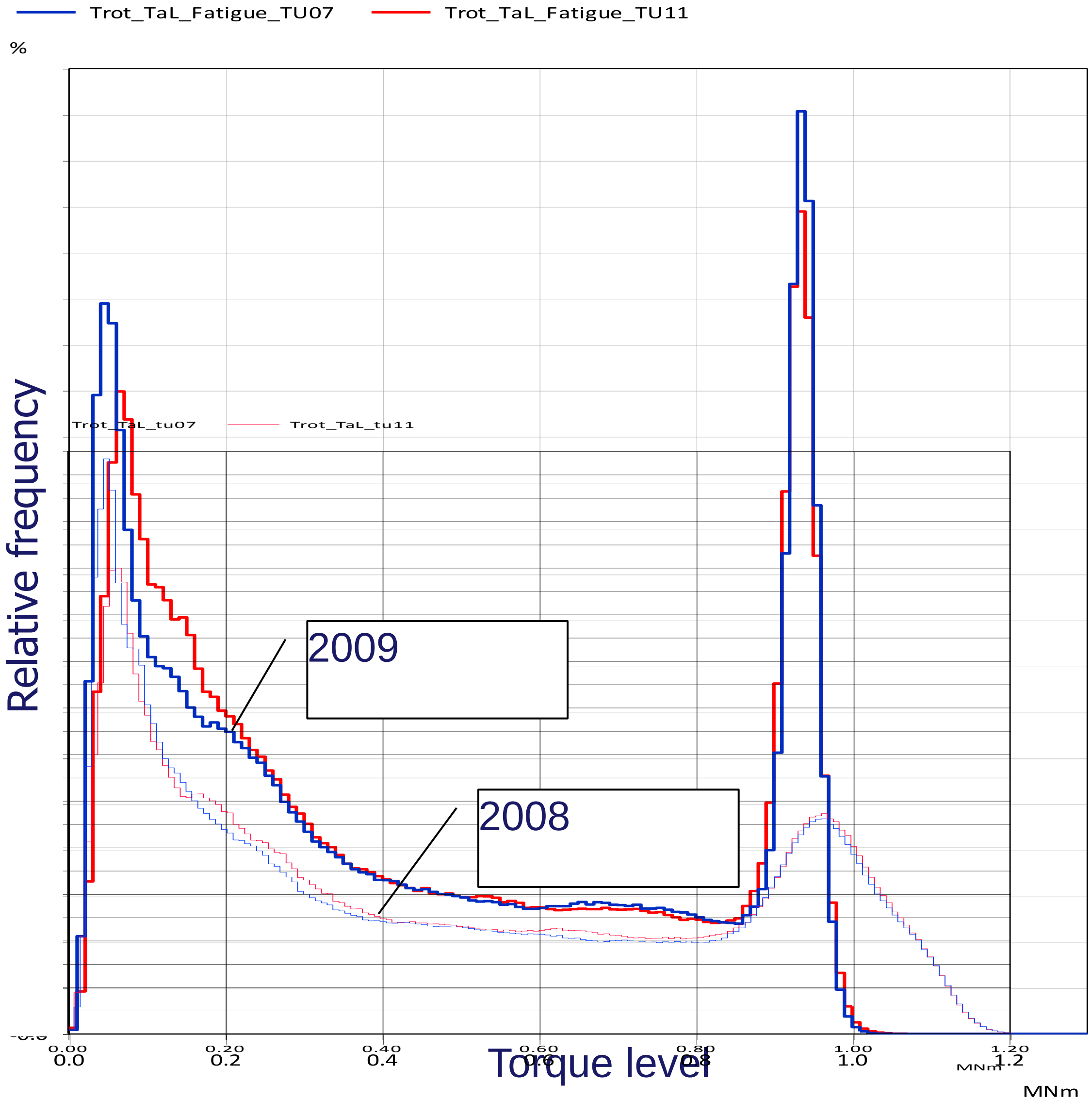
Impact clearly visible in Torque Load Range Spectra

TU 7%

TU11%

DEWI Quality by Know-how.

STEP 6: data processing



Impact clearly visible in Time @ Level Plots

DEWI Quality by Know-how.

Conclusions

- sensitivity studies to define relevant model input parameters (like inertia, stiffness, damping) are important to setup measurement campaigns
- measurements for model parameter validation have been carried out
- different methods to determine eigenfrequencies, stiffness, damping and intertia have been developed and applied
- stiffness values are reproduced
- all methods show similar trends with respect to inertia and damping values
- further investigations on the applied methods are needed

Authors

Birte-Marie Ehlers, Florian Stache

SUZLON Energy GmbH, Rostock, Germany, +49 381 203578 592, birte.ehlers@suzlon.com, florian.stache@suzlon.com,

Kris Smolders, Joris Peeters

Hansen Transmissions International nv, Lommel, Belgium, +32 11 54 9412, KSmolders@HansenTransmissions.com, peeters@hansentransmissions.com

Thomas Hequet,

Stiftungslehrstuhl Windenergie, Stuttgart, Germany, +49-711-685 68240, thomas.hecquet@ifb.uni-stuttgart.de

Holger Söker, Oscar Monux,

DEWI GmbH, Wilhelmshaven, Germany, +49 4421-4808-825, h.soeker@dewi.de, o.monux@dewi.de

Thank you!

SUZLON
POWERING A GREENER TOMORROW

Hansen® TRANSMISSIONS

SWE Stiftungslehrstuhl Windenergie am Institut für Flugzeugbau

DEWI

protest

COOPERATION