



ANDRITZ HYDRO SRL, SCHIO (I)

STRESSES AND FATIGUE LIFE BASED ON INDIRECT MEASURES

PADOVA, 18/09/2019 – HYDROMATTERS 4.0 – CLAUDIO BARON

ANDRITZ

ENGINEERED SUCCESS

CHAPTER OVERVIEW



01 ANDRITZ COMMITMENT IN NEW TECHNOLOGIES

02 INDIRECT MEASUREMENTS ?

03 THE MEASURING SYSTEM

04 STRESS STATES,
“VIRTUAL GAUGING”

05 FATIGUE LIFE CALCULATION

06 CONCLUSIONS,
FUTURE DEVELOPMENTS

ANDRITZ COMMITMENT IN NEW TECHNOLOGIES



The global energy market is changing



Hybrid Battery Technology

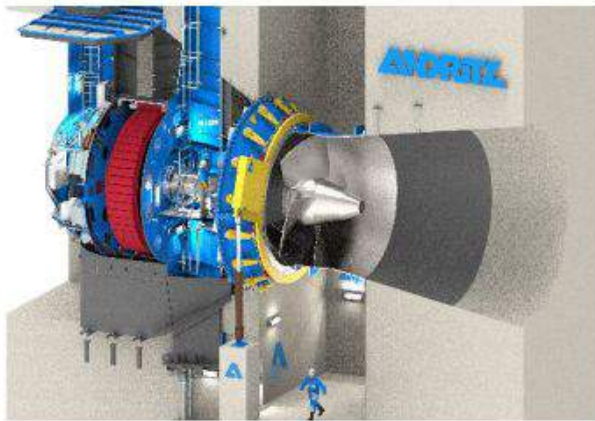


Operation & Maintenance advanced digitalized services

ANDRITZ COMMITMENT IN NEW TECHNOLOGIES



Combining the advantages of hydropower and battery technology



+



=



Advantages:

- High efficiency
- Proven technology
- Smooth operation
- Renewable source of energy

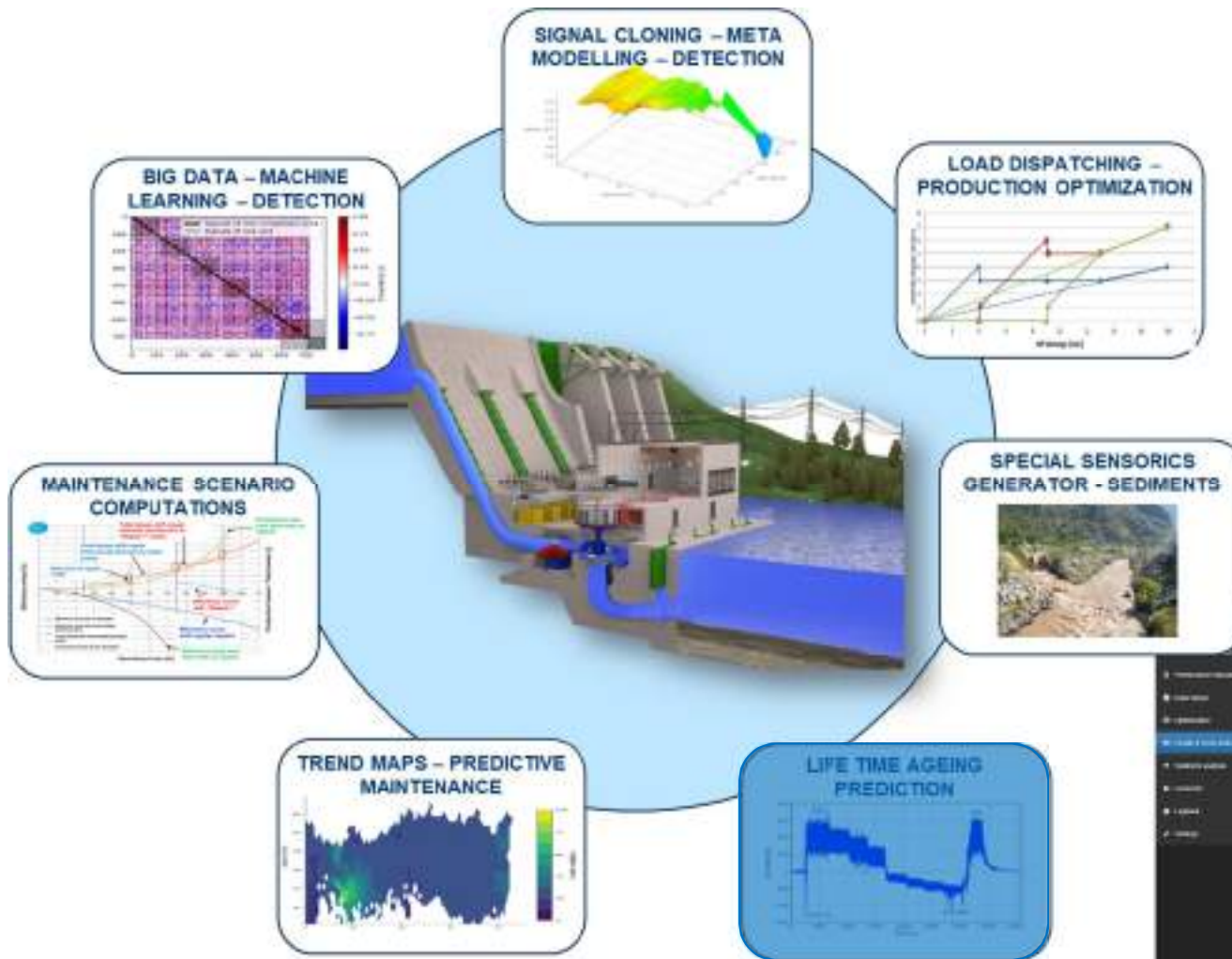
Advantages:

- Short term storage capacity
- Fast response time
- Highest flexibility
- Load balancing

Advantages:

- Wider energy range
- Fastest response time
- Flexible power
(also in part load at start-up)
- Highest operational flexibility

ANDRITZ COMMITMENT IN NEW TECHNOLOGIES



CHAPTER OVERVIEW



01 ANDRITZ COMMITMENT IN NEW TECHNOLOGIES

02 INDIRECT MEASUREMENTS ?

03 THE MEASURING SYSTEM

04 STRESS STATES,
“VIRTUAL GAUGING”

05 FATIGUE LIFE CALCULATION

06 CONCLUSIONS,
FUTURE DEVELOPMENTS

INDIRECT MEASUREMENTS? ... THE SCOPE



Mechanical fatigue of an existing rotating assembly (“shaftline”)

Why bothering with fatigue on a shaftline?

Aren't the shafts designed for infinite life?

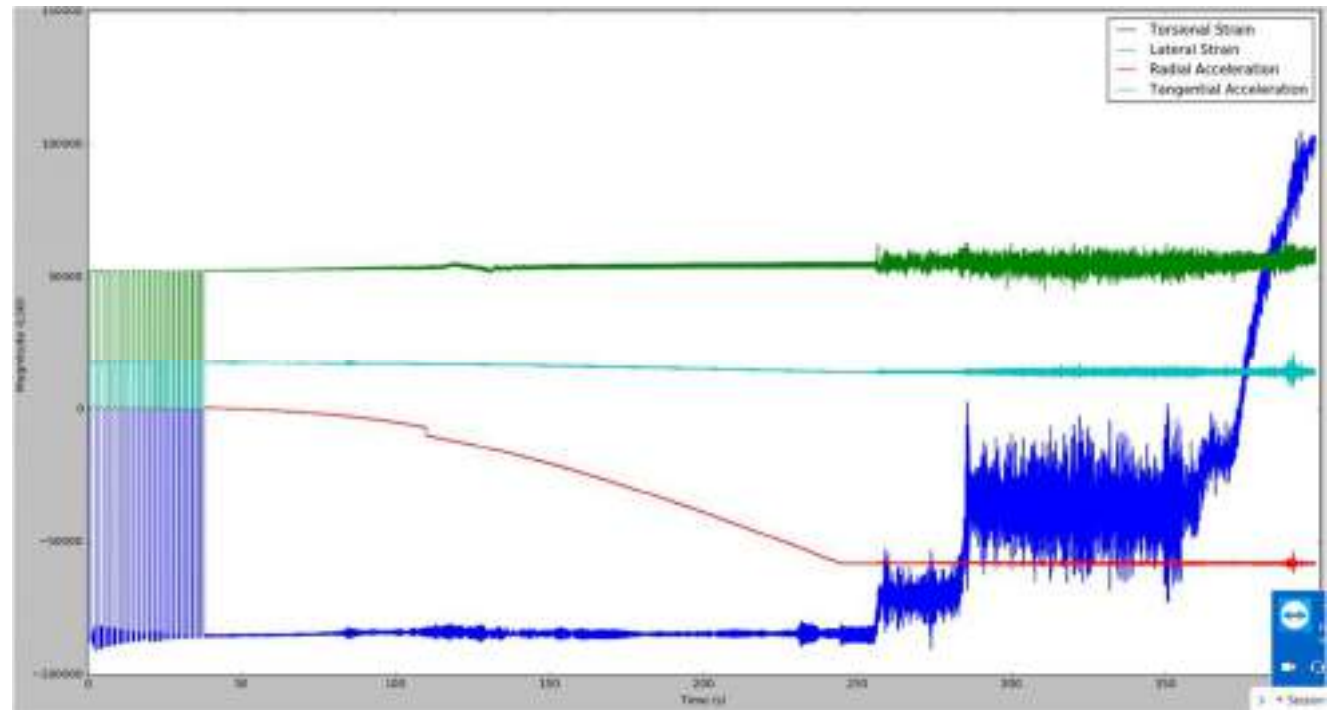
High torsion stress oscillations detected during startup phases:

$$\Delta\tau \approx 12 \text{ [MPa]}$$

$$\tau_{\text{nom}} = 37.9 \text{ [MPa] @ 260 [MW]}$$

→ How do this cope with the original design hypotheses?

A partnership project...



INDIRECT MEASUREMENTS? ... THE SCOPE



→ Stress in “critical” locations



Not accessible !!

→ “No” downtime availability



**No complex system;
Impossibility to remove /
dismantle elements**



CHAPTER OVERVIEW



01 ANDRITZ COMMITMENT IN NEW TECHNOLOGIES

02 INDIRECT MEASUREMENTS ?

03 THE MEASURING SYSTEM

04 STRESS STATES,
“VIRTUAL GAUGING”

05 FATIGUE LIFE CALCULATION

06 CONCLUSIONS,
FUTURE DEVELOPMENTS

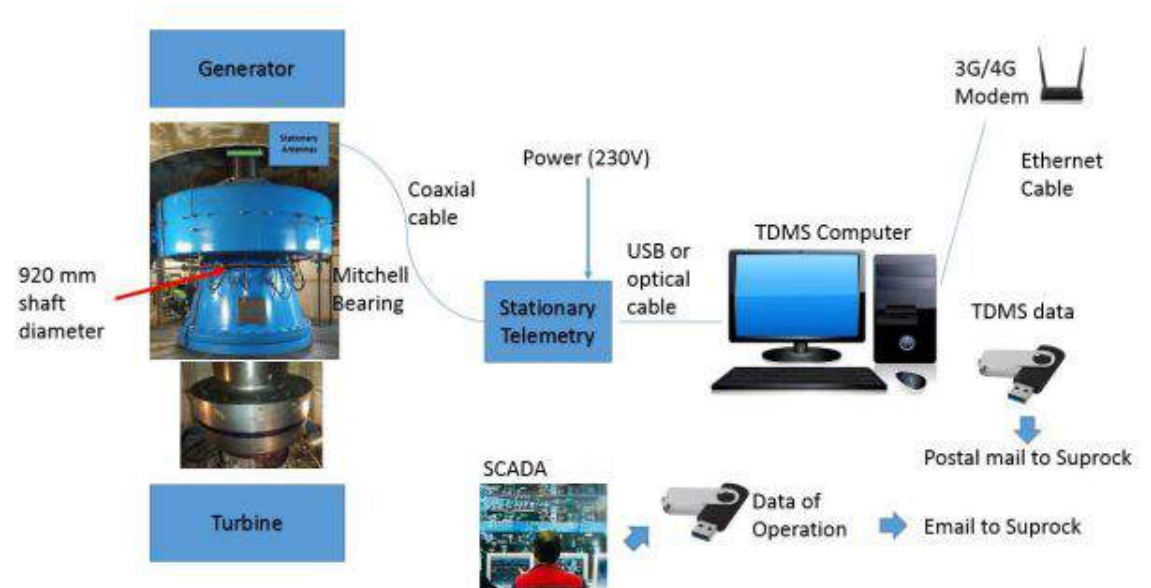
THE MEASURING SYSTEM



- Implemented by the Partner in this research project
- “package” fixed on the outer surface of the shaft
→ “Undisturbed” section of the machine’s intermediate shaft



- Signals:
 - 2x strain-gages: tangential and axial strains
→ resp. torsion, and bending + normal strain (combined)
 - 2x accels: tangential and radial



CHAPTER OVERVIEW



01 ANDRITZ COMMITMENT IN NEW TECHNOLOGIES

02 INDIRECT MEASUREMENTS ?

03 THE MEASURING SYSTEM

04 STRESS STATES,
“VIRTUAL GAUGING”

05 FATIGUE LIFE CALCULATION

06 CONCLUSIONS,
FUTURE DEVELOPMENTS

STRESS STATES – “VIRTUAL GAUGING”



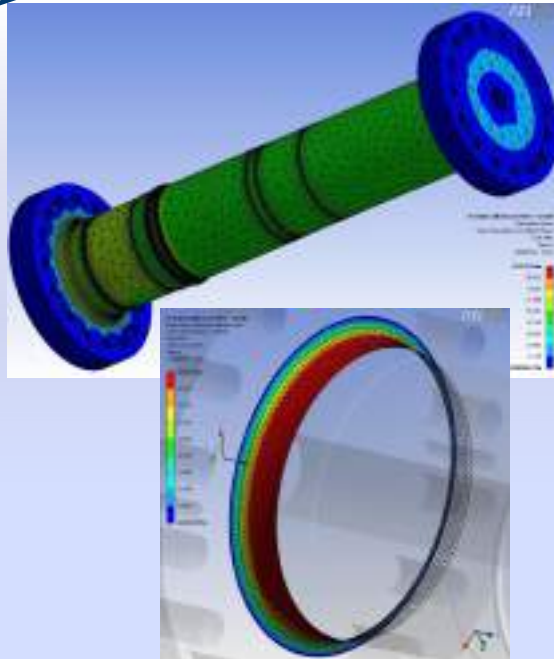
Physical quantity (STRESS)
referred to an «average»
undisturbed section

Static part

Independent from the eigen-
response of the system

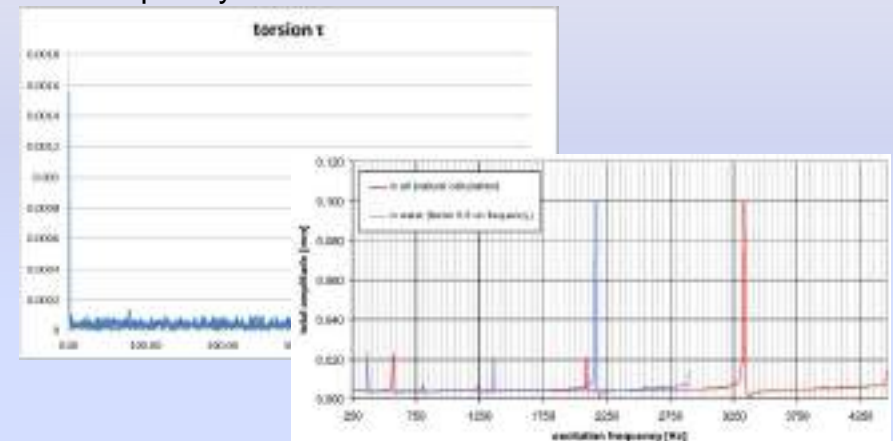
Calculation of the stress-
concentration factors
(analytical, or FEM)

Physical quantity (STRESS)
referred to each «critical»
section (ex.: transition fillets,
etc...)



Dynamic part

Dependent on the system's dynamic eigen-
response: HRA, transfer functions dependent on the
frequency

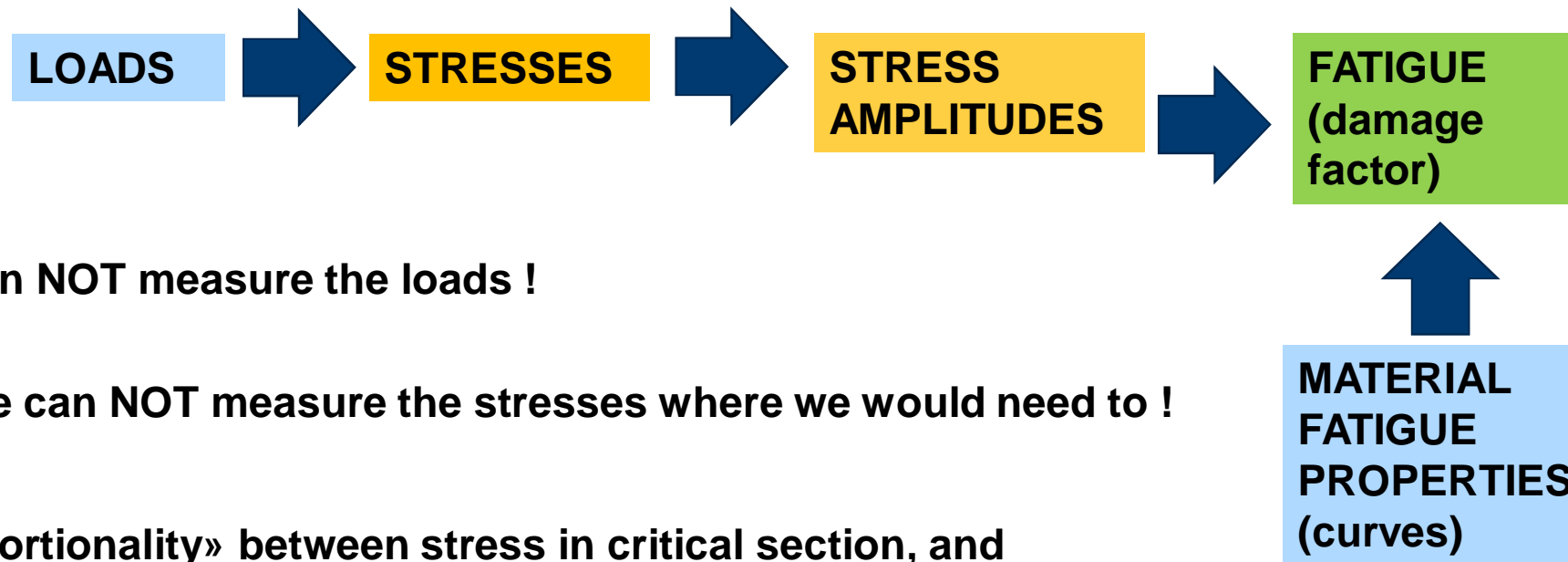


An Harmonic-Response Analysis from DC (0 [Hz]) up to the max «interesting» frequency
(participant mass fraction at least 99% for all DOFs) can cover both aspects

STRESS STATES – “VIRTUAL GAUGING”



The trivial process:



We can NOT measure the loads !

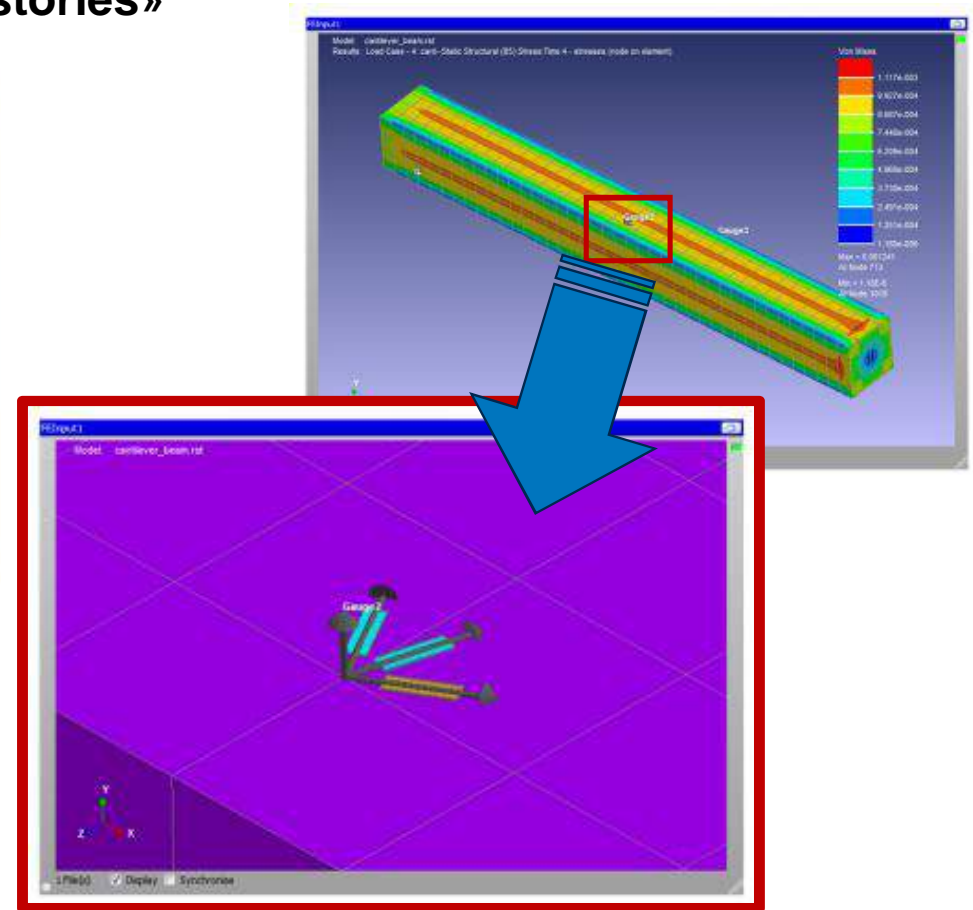
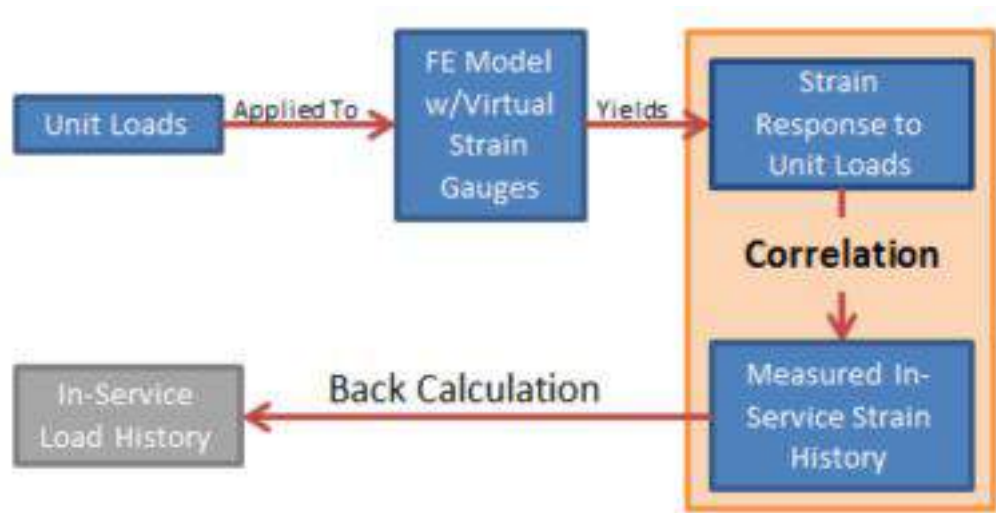
We can NOT measure the stresses where we would need to !

«Proportionality» between stress in critical section, and stress in the measured section, depends on the frequency (modal participation) ! → **not static-only calculation**

STRESS STATES – “VIRTUAL GAUGING”



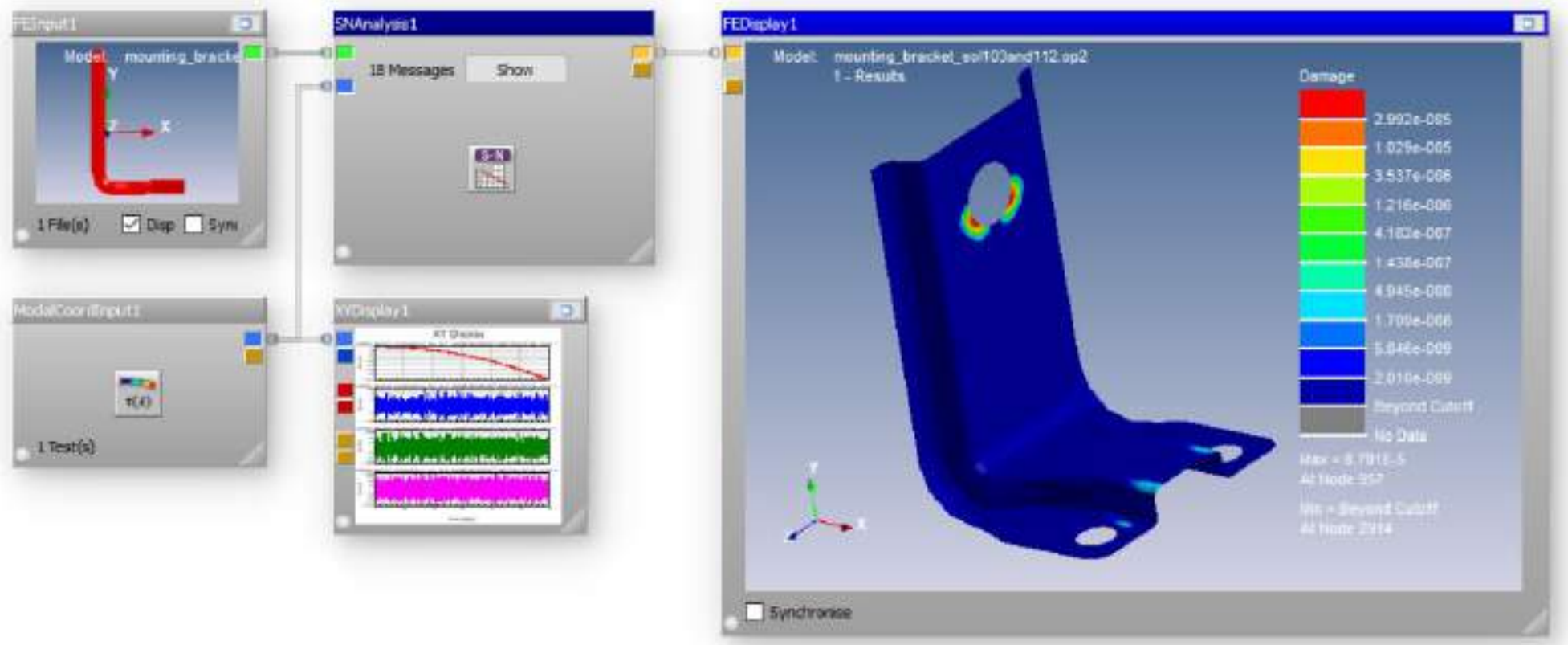
Loads from stresses: «Reconstructing Load Histories»



STRESS STATES – “VIRTUAL GAUGING”



Calculating responses: modal superposition





STRESS STATES – “VIRTUAL GAUGING”

Previous processes can be «assembled» together → direct «full dynamic» stress reconstruction by modal superposition

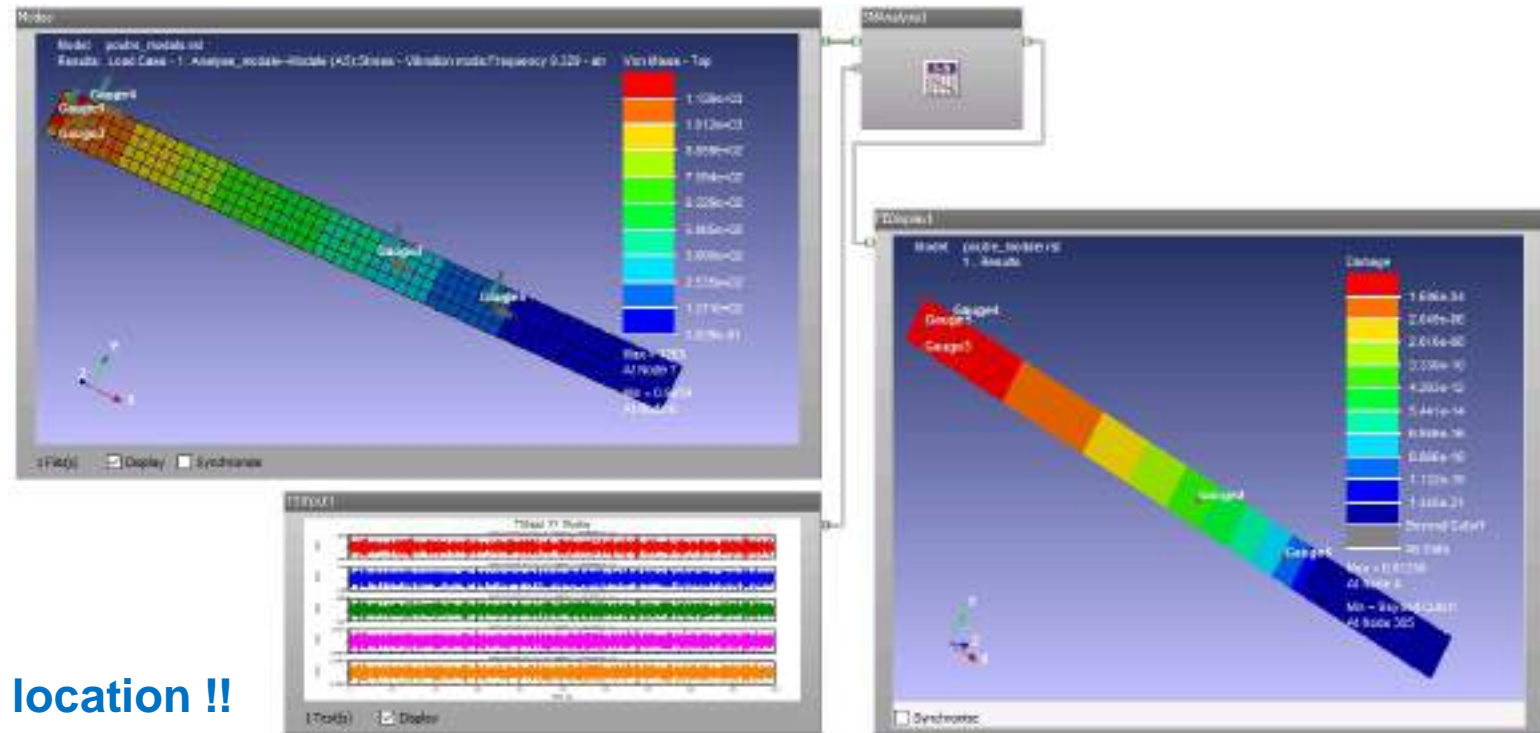
→ The process works if...

... there are sufficient gauge locations.

→ correctly characterize the modes of interest.

In our study, there is only 1 location !!

→ Direct calculation by modal superposition is **impossible**



STRESS STATES – “VIRTUAL GAUGING”

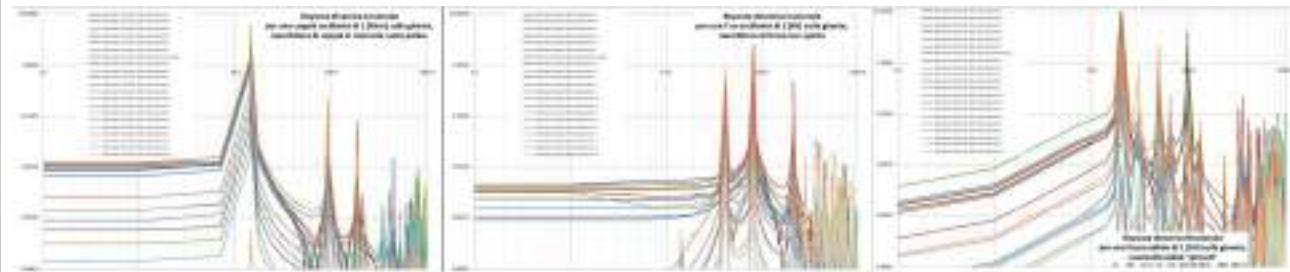
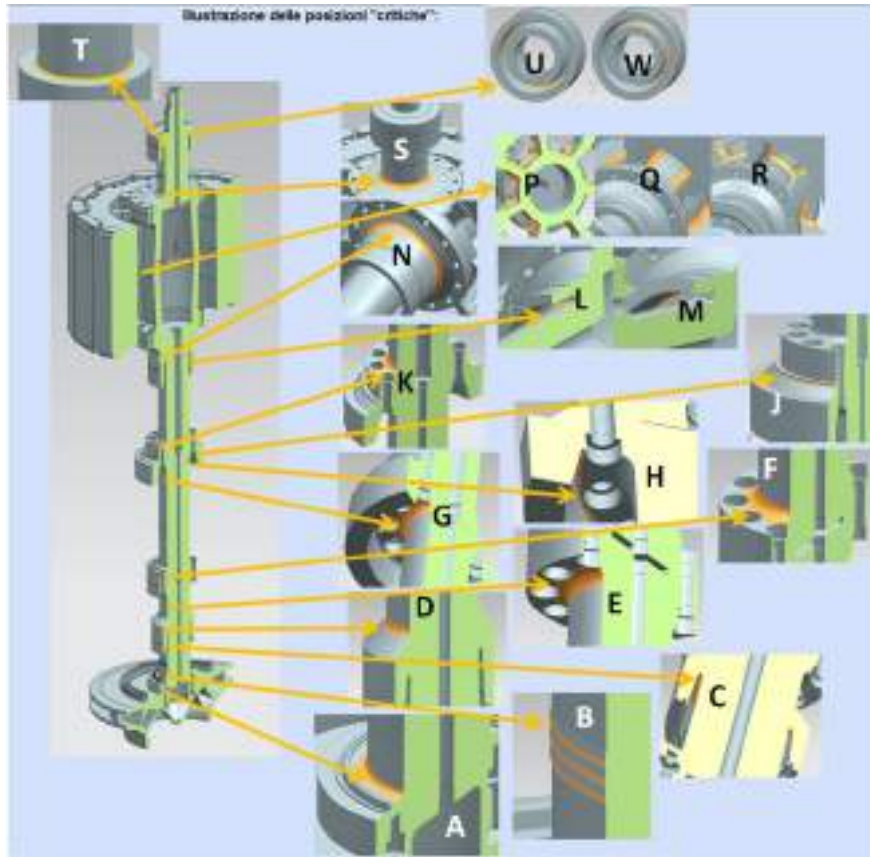


Playing around with transfer functions: indirect dynamic reconstruction by multiple virtual loads and Fourier Filtering

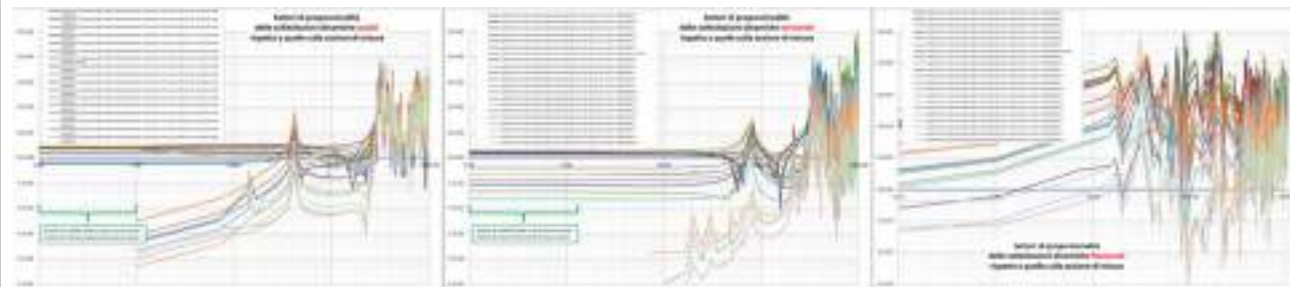
In each of the «critical sections» + measured section:

3 Harmonic Response Analyses: torsion, bending, axial

→ return the stress amplitudes for a unit «effector» (torque / force) depending on the frequency



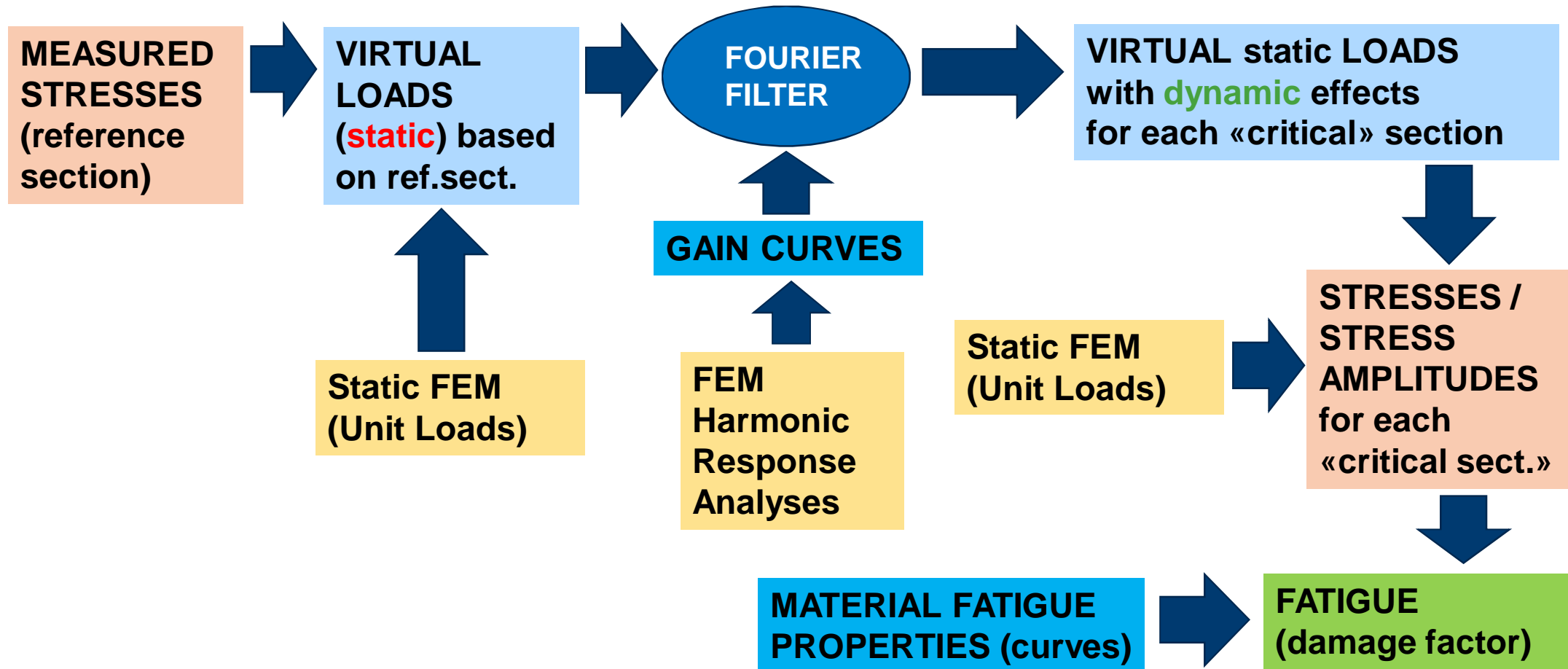
Related to the measured section (as a function of frequency)
→ **dynamic relative response curves (GAIN CURVES)**



STRESS STATES – “VIRTUAL GAUGING”



Our reworked process schema...:



CHAPTER OVERVIEW



01 ANDRITZ COMMITMENT IN NEW TECHNOLOGIES

02 INDIRECT MEASUREMENTS ?

03 THE MEASURING SYSTEM

04 STRESS STATES,
“VIRTUAL GAUGING”

05 FATIGUE LIFE CALCULATION

06 CONCLUSIONS,
FUTURE DEVELOPMENTS

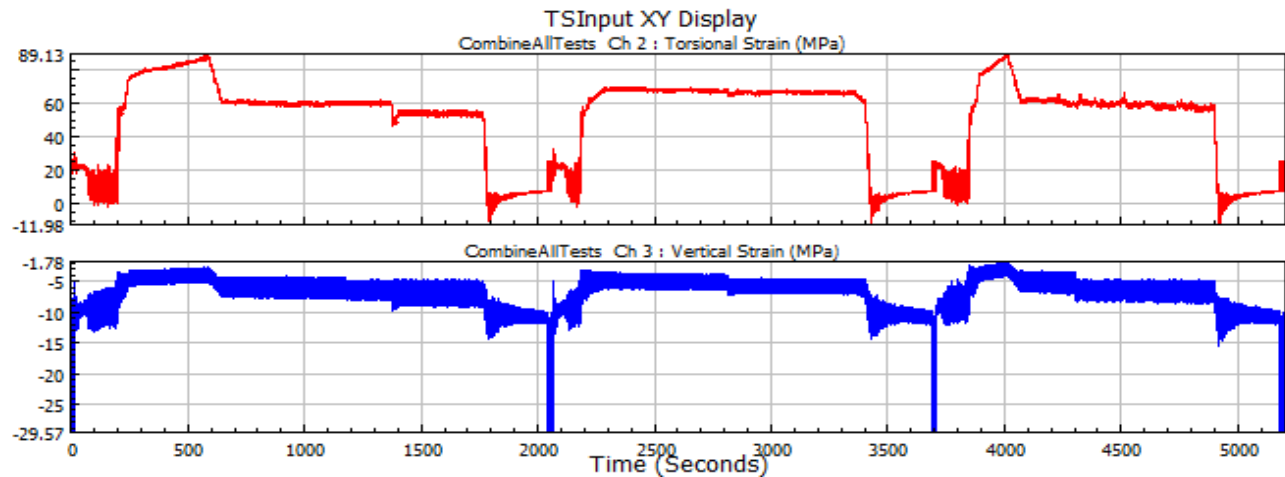
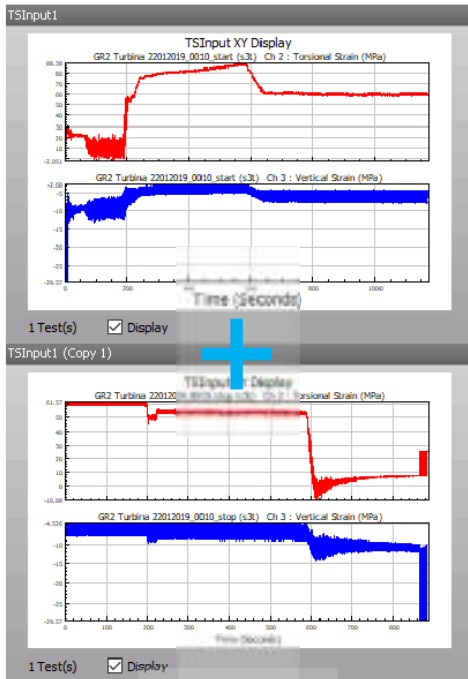
FATIGUE LIFE CALCULATION



1. Assembling data series for the analyzed period

The measuring system saves raw data files:

- For the entire startup sequence
- For the entire coast-down sequence
- Periodically in defined intervals, during operation



- Reassembling whichever time history → daily operation for example
- Or treating an event separately → e.g. determine fatigue associated to «running in pump at full-load»

FATIGUE LIFE CALCULATION



2. Signal pre-conditioning

- From measuring system → torsion OK
→ bending not distinguishable from normal («everything is axial»)

Knowledge + Numerical analyses → characteristic frequencies



Separate bending from normal axial based on filtering

Industrialized solution: more sensors → symmetric vs antimetric components

- Scaling error between electrical magnitudes and Engineering Units [MPa]

Analytical correlations based on known situations / physics of the machine



Rescale to physically meaningful

FATIGUE LIFE CALCULATION



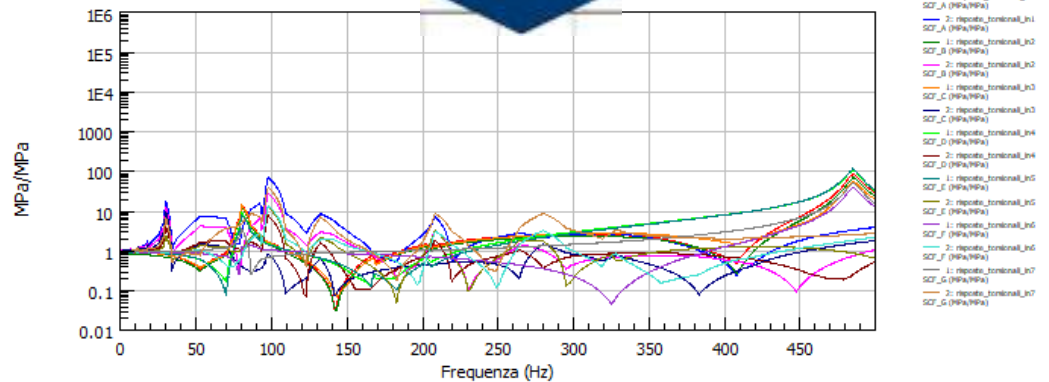
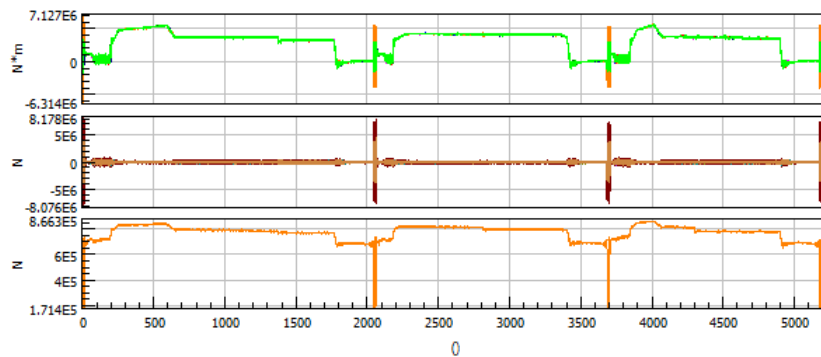
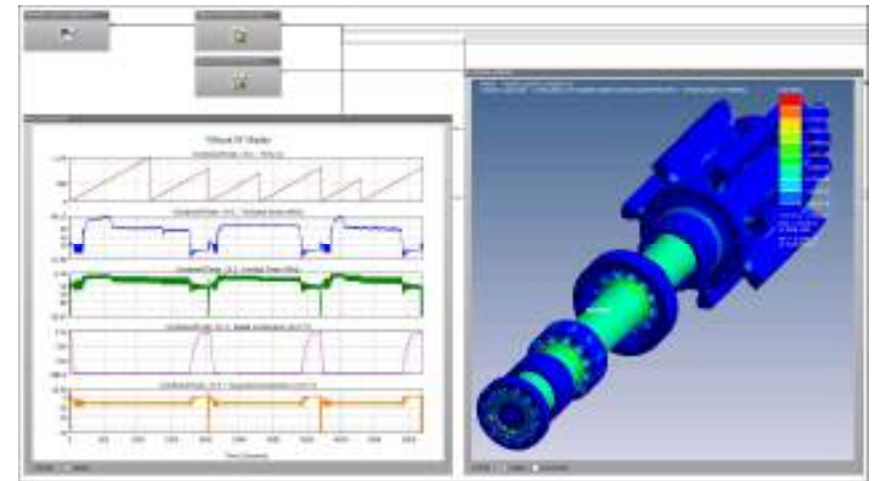
3. Calculating the time-series of the «virtual loads» for each analyzed section

a) First «base» loads reconstruction based on purely static calculations:

stresses measured on the reference section,
+ FEM static model (3 load cases for torsion,
bending, and axial load)
= common loads set

b) Modulation to incorporate dynamic effects:

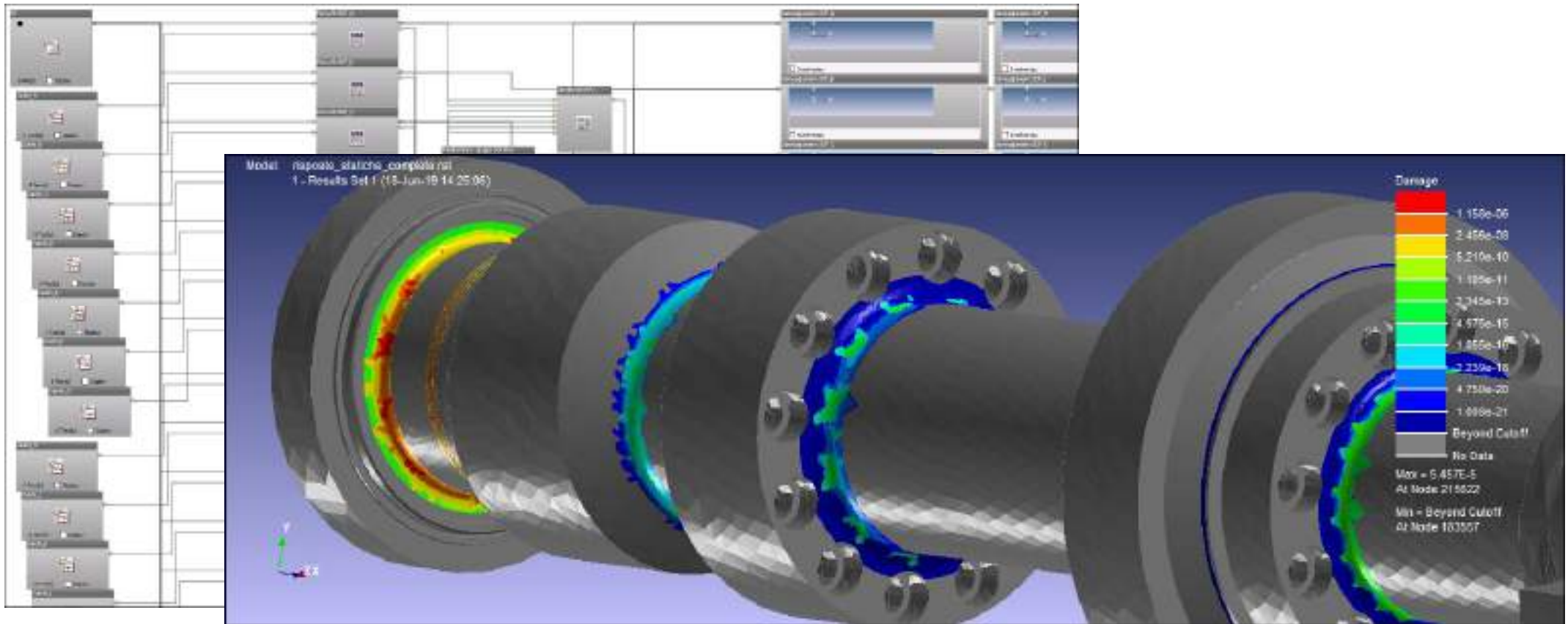
common loads set,
* gain functions (each sect.)
= virtual loads (each sect.)



FATIGUE LIFE CALCULATION



4. Calculating the fatigue damage associated to the time-history



FATIGUE LIFE CALCULATION



5. Cumulating the fatigue damage progressively calculated

Numero di ripetizioni considerato per la TS elaborata: 1

Aggiorna Danneggiamento
sulla base della Time Series elaborata con nCode/DesignLife

In case of calculation for a «categorized event» (e.g. «startup to synchronization», «shut-down», «turbine full-load»...), allows to calculate D for a defined number of repetitions
 → **Useful for determination of previous accumulated fatigue for example**

Imports the D_i tables from the last executed calculation, multiplies by the repetitions, sums it node by node to the previous D_i , and determines the new maximum cumulative D .

CHAPTER OVERVIEW



01 ANDRITZ COMMITMENT IN NEW TECHNOLOGIES

02 INDIRECT MEASUREMENTS ?

03 THE MEASURING SYSTEM

04 STRESS STATES,
“VIRTUAL GAUGING”

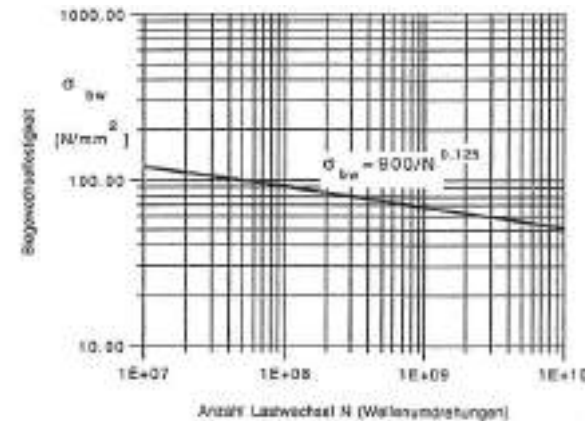
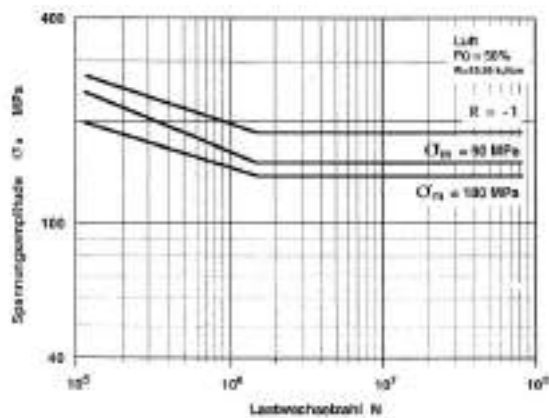
05 FATIGUE LIFE CALCULATION

06 CONCLUSIONS,
FUTURE DEVELOPMENTS

CONCLUSIONS, FUTURE DEVELOPMENTS



- Fatigue induced by **dynamic loads** is **not negligible**
- However, **damage** only appears in «**wet**» areas (no fatigue resistance):



- The analyzed shaftline, dimensioned with **Andritz' criteria / standard load spectra** (former DPEW, Sulzer, VA-Tech methodology), **proves safe also with operation data**
- **Added value of the project:** the calculation is **adaptive** to any modification in the operation itself (# starts/stops, primary reserve in turbine operation, etc...).

CONCLUSIONS, FUTURE DEVELOPMENTS



- Semi-automatized calculation (batch processing), but launched manually
- Hits the targets of the partnership program, but is not «industrialized»



- Technical issues to be solved **on measuring side:**
 - Correct discrimination between bending and normal effects
 - Correct scaling of the gauges to engineering units
 - Enhancing the synchronization with PLC signals (esp. Startup)
- Developments **on calculation / monitoring side:**
 - Fully automatized process
 - Direct time-history vs. rainflow-based fatigue damage calculation ?
 - **Inside DiOMera = Technology Module:** «plugin» or complete porting ?
 - **Inside DiOMera = Technology Module:** from KDI (current) to KTI (preemptive)

LEGAL DISCLAIMER



© ANDRITZ AG 2019

This presentation contains valuable, proprietary property belonging to ANDRITZ AG or its affiliates (“the ANDRITZ GROUP”), and no licenses or other intellectual property rights are granted herein, nor shall the contents of this presentation form part of any sales contracts which may be concluded between the ANDRITZ GROUP companies and purchasers of any equipment and/or systems referenced herein. Please be aware that the ANDRITZ GROUP actively and aggressively enforces its intellectual property rights to the fullest extent of applicable law. Any information contained herein (other than publically available information) shall not be disclosed or reproduced, in whole or in part, electronically or in hard copy, to third parties. No information contained herein shall be used in any way either commercially or for any purpose other than internal viewing, reading, or evaluation of its contents by recipient and the ANDRITZ GROUP disclaims all liability arising from recipient’s use or reliance upon such information. Title in and to all intellectual property rights embodied in this presentation, and all information contained therein, is and shall remain with the ANDRITZ GROUP. None of the information contained herein shall be construed as legal, tax, or investment advice, and private counsel, accountants, or other professional advisers should be consulted and relied upon for any such advice.

All copyrightable text and graphics, the selection, arrangement, and presentation of all materials, and the overall design of this presentation are © ANDRITZ GROUP 2018. All rights reserved. No part of this information or materials may be reproduced, retransmitted, displayed, distributed, or modified without the prior written approval of Owner. All trademarks and other names, logos, and icons identifying Owner’s goods and services are proprietary marks belonging to the ANDRITZ GROUP. If recipient is in doubt whether permission is needed for any type of use of the contents of this presentation, please contact the ANDRITZ GROUP at welcome@andritz.com.