VMS platform

impeller blade vibration and rotor torsional vibration monitoring

Ales Krutina, Jindrich Liska

About the company

LOGIC ELEMENTS headquarters in Pilsen
LOGIC ELEMENTS is member of JABLOTRON GROUP

About the Jablotron Group

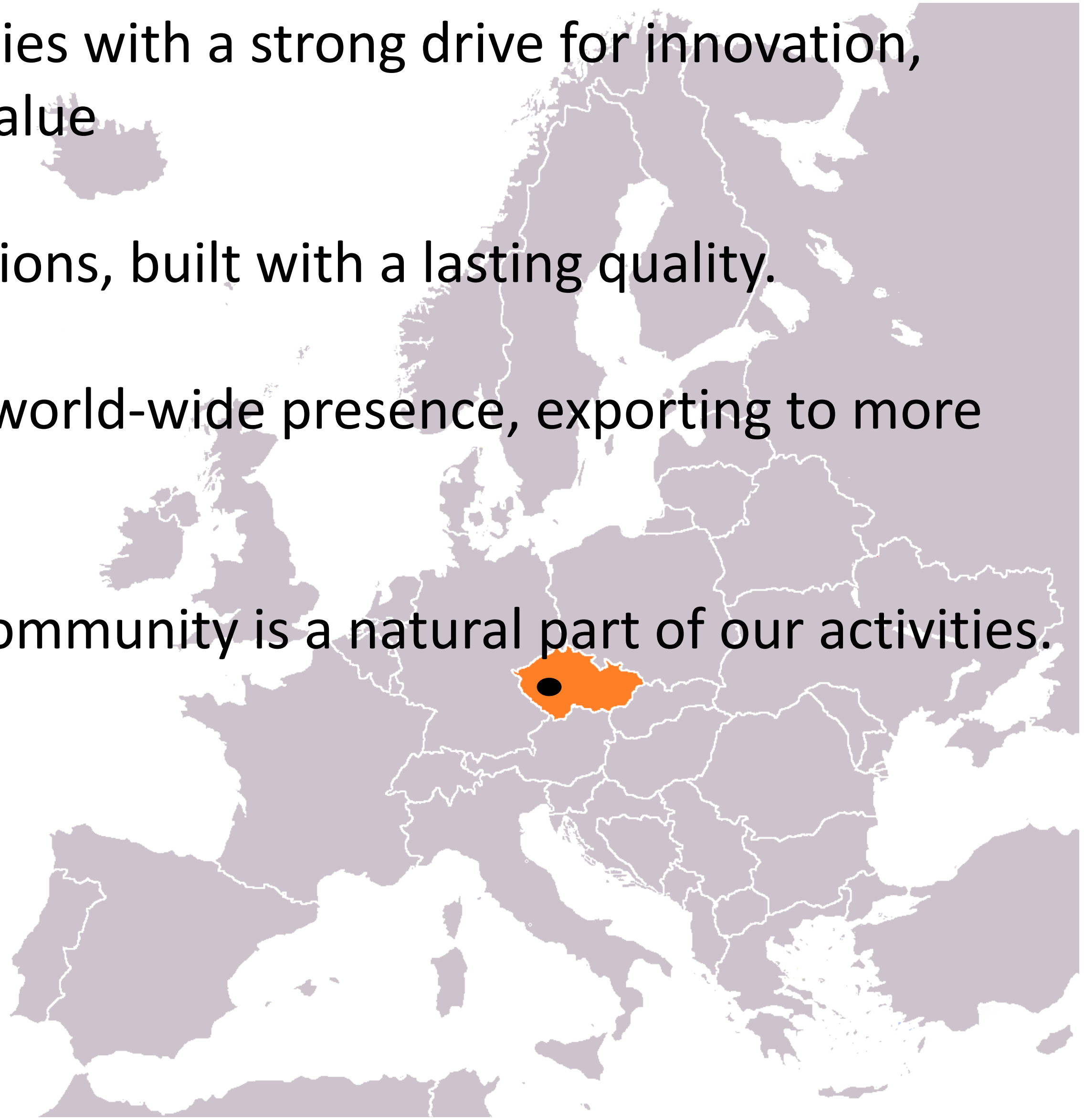
- We are a growing group of independent companies with a strong drive for innovation, creating products and services that brings a real value

- We focus on good **TECHNO** but also **LOGIC** solutions, built with a lasting quality.

- We are a Czech Republic based company with a world-wide presence, exporting to more than 80 countries.

- And it´s not only about business - helping the community is a natural part of our activities.

- 22 companies in the group
- Facilities in Europe and China



Manufacturing facilities

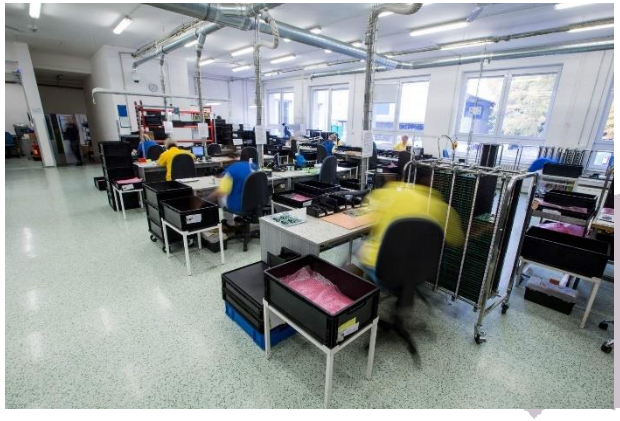
JabloPCB.cz

RTG Inspection

Automatic assembly

Automatic output testing

Packing & assembly



Warehouse - 4500m2

About the Jablotron Group

- LE – Design house for embedded systems – 15 FTE (Pilsen site)
- TechFass – Access control systems (10 FTE)
- JabloNet – 20 FTE Cloud infrastructure maintanence
- Jablotron Security – 24h/7days monitoring center and security cars (170 FTE)
- Jablotron Living Technologies – Heating, Boilers, Recuperation units (25 FTE)
- Jablotron Cloud Services (42 FTE)
- Jablotron Alarms (177 FTE)

LE projects

Customer: ZAT, control systems for nuclear power plant
- Power supply unit
- OVER RPM safety unit
- Diagnostic card unit

CERN collaboration member
- JABLOTRON EDU KIT for schools (particlecamera.com)

technology

Who are we ?

Aleš Krutina, Ph.D.

- Co-Owner & Managing director of Logic Elements
- CTO of Jablotron Group, Board member
- 10 years of experiences in power systems

Jindřich Liška, Ph.D.

- Expert in the field of Vibration diagnostics
- 15 years of experiences

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Impeller blade vibration monitoring

Motivation

The free standing and especially shrouded or bandaged blades are often used in turbomachines of large capacity, mainly in steam turbines.

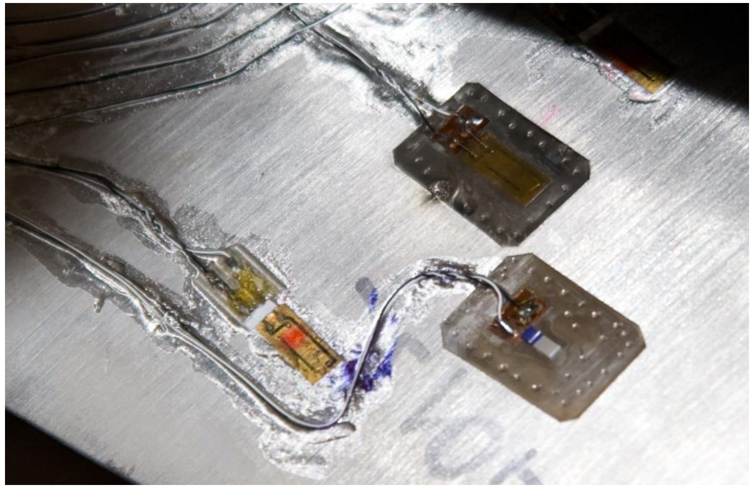
To avoid accidents with extensive economic losses, there appears an urgent need to equip at least the last stage of low pressure turbine (with respect to the dimensions of the installed blades) with monitoring to provide information of blades vibration, their damage and residual lifetime.

Blade monitoring techniques

Used techniques for blade monitoring

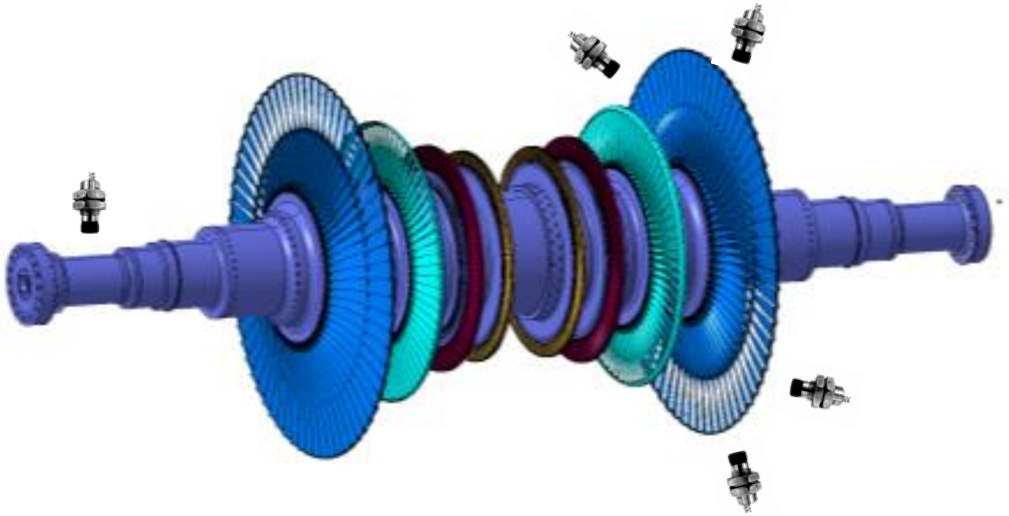
Strain gauges

- 👍 Measurement of relative deformation
- 👍 Direct evaluation of mechanical stress
- 👎 Short lifetime
- 👎 Limited number of measured blades



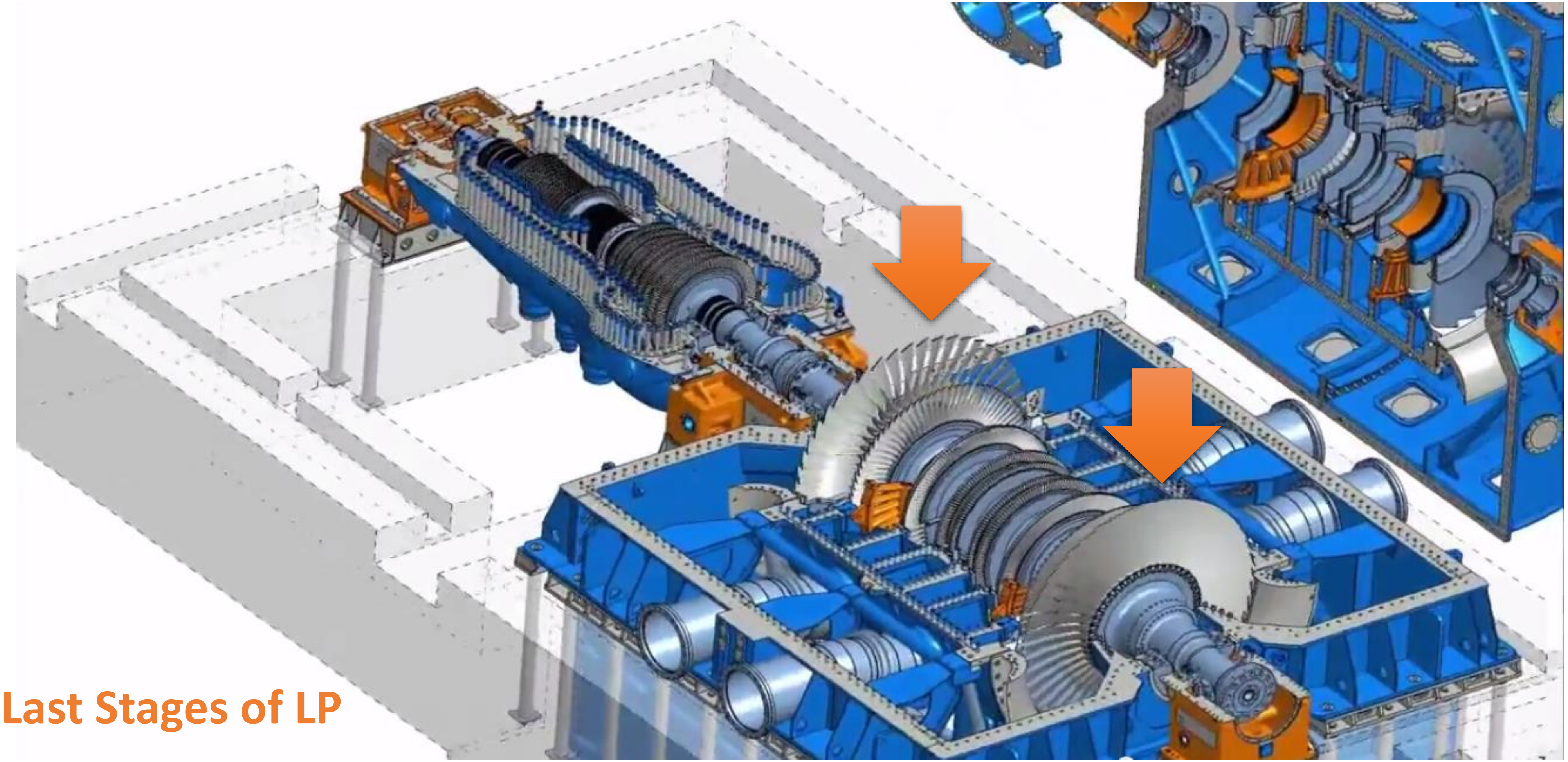
Blade Tip-Timing

- 👍 Measurement of all blades
- 👍 Able to distinguish different NDs
- 👍 Long lifetime
- 👍 Evaluation of mechanical stress
- 👎 High frequency sampling
- 👎 Difficult installation



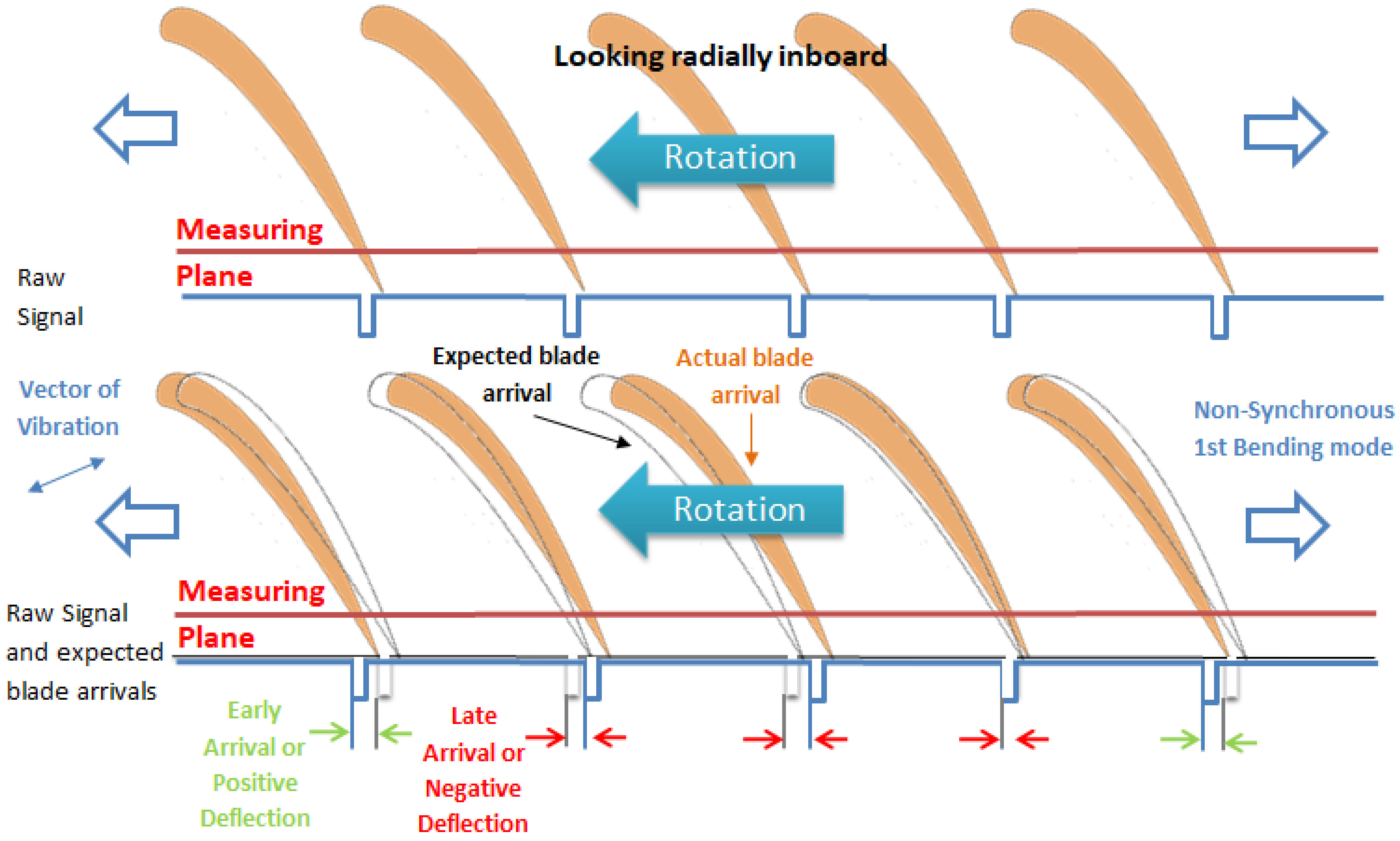
Double casing steam turbine – 150 MW

Overview example

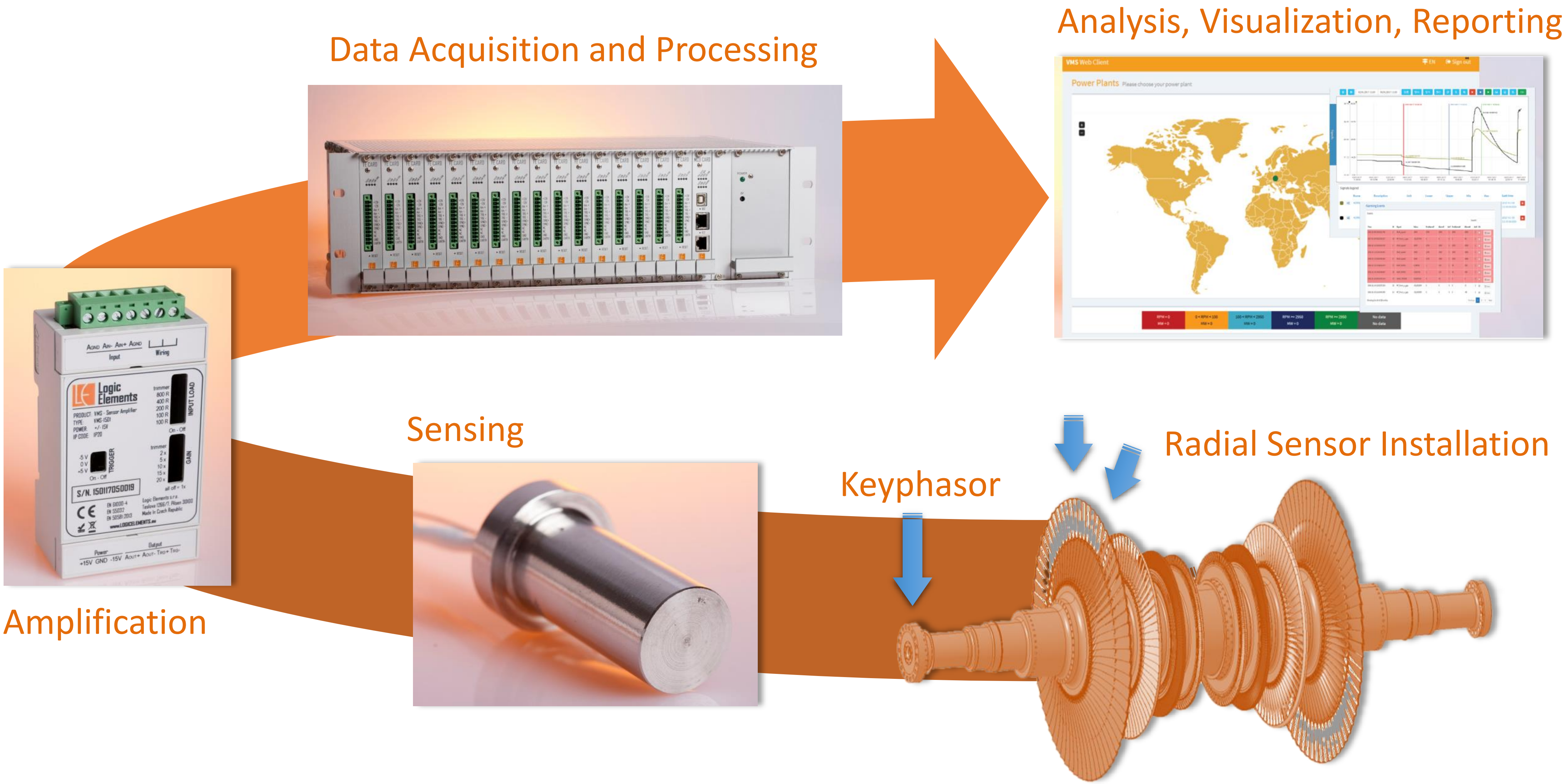


Last Stages of LP

Blade Tip Timing measurement principle



Blade Tip Timing measurement principle



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VMS Platform

Sensor (Inductance Sensor, Temperature measurement included)

Optimally suitable for the use at all kind of turbomachines. Measuring quantities includes:

- Blade vibration measured from Time of Arrival signals
- Blade untwisting and angle between leading and trailing edge
- Blade lean
- Shaft speed
- Air gaps between rotating and stationary parts (indirect measurement has to be calibrated)
- Temperature measurement
- Torsional shaft vibration

Parameter	Value
Cable length	15 m
Temperature	225 °C
Head diameter	14 mm
Flange	direct

Optionally includes PT100 temperature sensor

Sensor Amplifier (VMS-1501)

With the VMS-1501 you can choose a couple of output signals to use such as Triggered differential digital signal, Differential raw analog signal from the sensor or both. Functions and benefits:

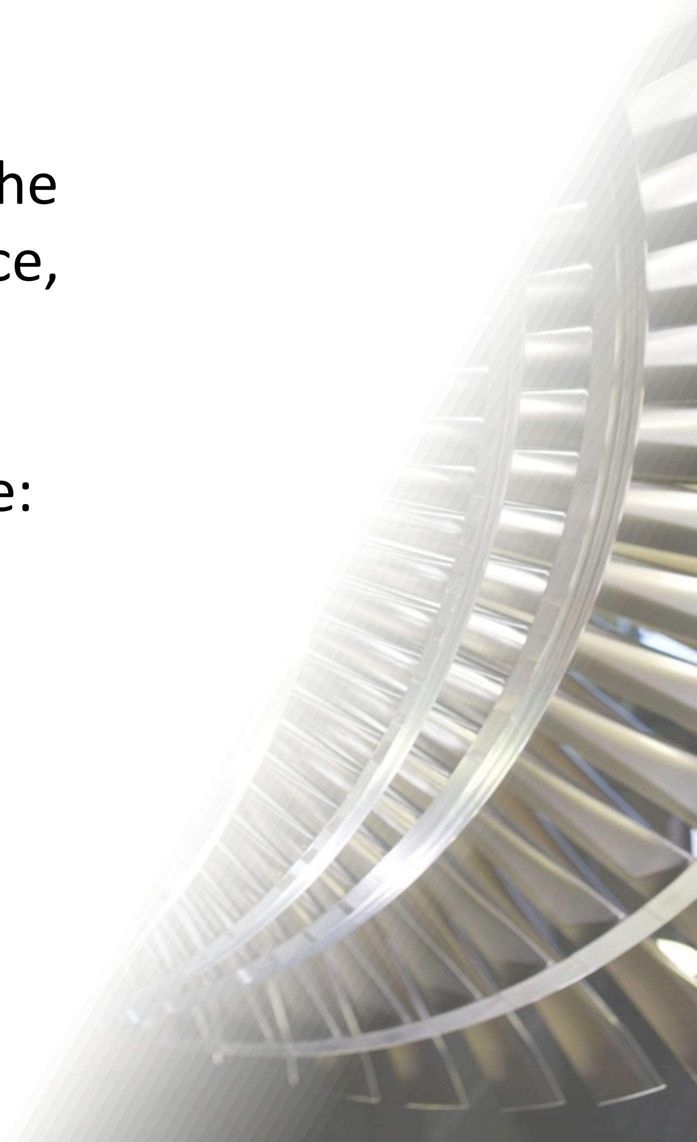
- DIN mounting (3 modules)
- 1 Analog Input (sensor)
- 1 Digital output (RS485)
- 1 Analog Output (+/- 10V)
- Trigger Level Selection (+5V, 0V, -5V)
- Signal Gain Control (from 1x to 20x)
- Input Impedance Control (from 100R up to 1600R)
- Power Supply range from +-12V up to +- 15V

VMS – Description & Features

- Platform for measurement of blades vibration of steam turbine.
- 16x channel for sensors
- High accuracy
- Sampling frequency 100MHz /ch
- Ethernet communication to server
- 100 Mbps interface speed
- USB port for settings and diagnostics
- RS485 (galvanic isolation)

  for integration of 3rd party devices
- Width 19”, height 3U, depth 240 mm

VMS – Software



Software has been developed to meet the full range of blade vibration monitoring demands, from receiving and interpreting signals from the sensors (as processed by the pre-amp through the data console) to online monitoring of turbine system performance, including remote communication.

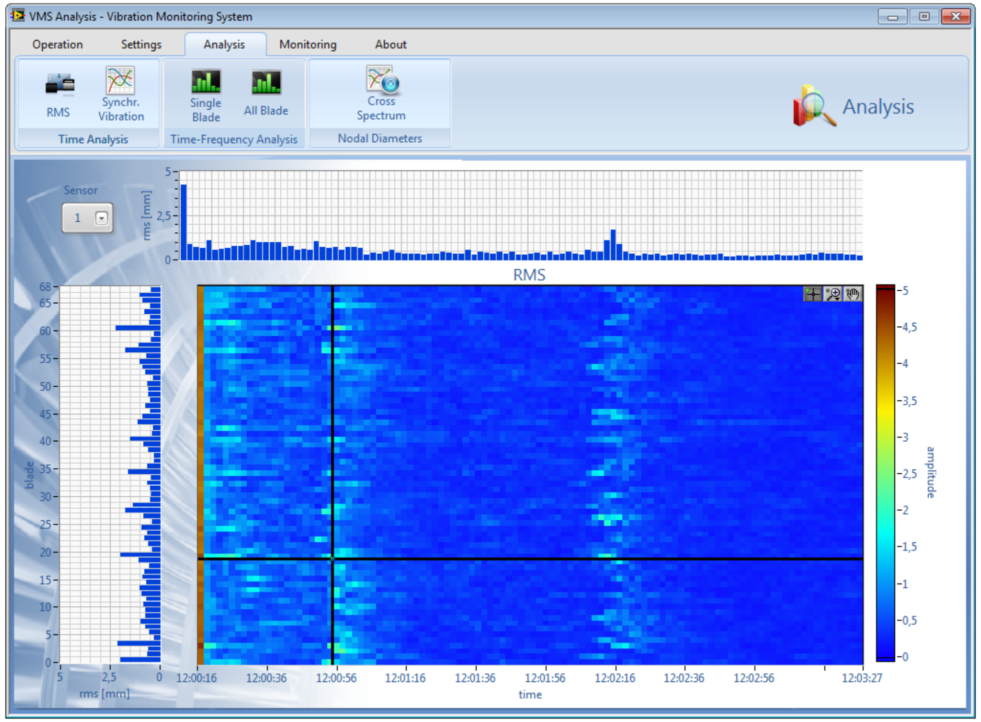
The major components of VMS software from Logic Elements are:

- LE-VMS-2100 - VMS SETUP
- LE-VMS-2101 - VMS COMPUTING CORE
- LE-VMS-2102 - VMS ANALYSIS
- LE-VMS-2200 - VMS WEB CLIENT

VMS ANALYSIS

- Sensor Status (correct number of pulses, arrival variability).
- Sensor Location Determination, based on user configuration or interblade spacing
- Circumferential Fourier fit (i.e. Order Tracking) using 3 or more sensors.

- Blade-by-blade viewing
- Results can be exported to a Campbell or SAFE diagram
- User-configurable data smoothing and processing features.
- Spectrogram display.
- Full 0-1kHz frequency analysis (identification of blade frequencies and nodal diameters).
- Non-integral Circumferential Fit performed for single blade a mplitudes.
- Results can be exported to a Campbell or SAFE diagram.



VMS WEB CLIENT

VMS WEB CLIENT provides

- remote access to VMS data and analysis results
- long-term trending of monitored synchrounous/asynchrounous phenomena
- available in any web browser – no installation needed
- offers a platform to store the diagnostic templates, graphs and analysis results for repeated analysis with new data or for sharing them with co-workers
- alarm management and settings
- user defined data visualization

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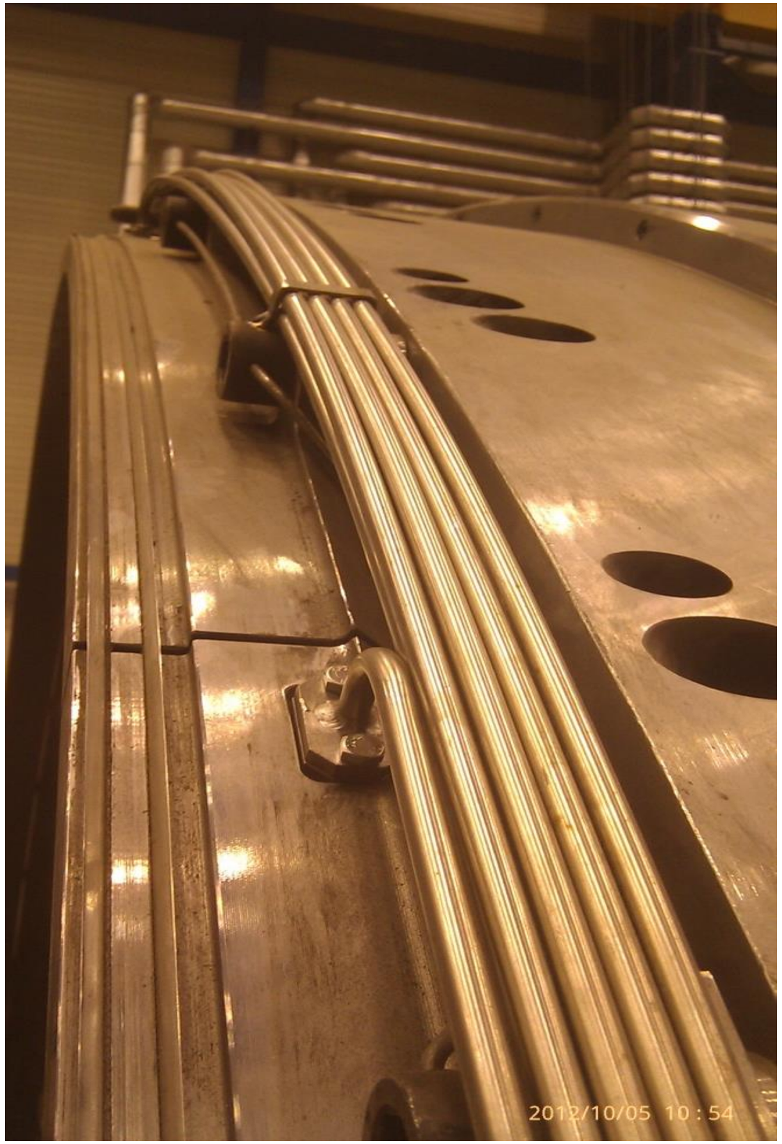
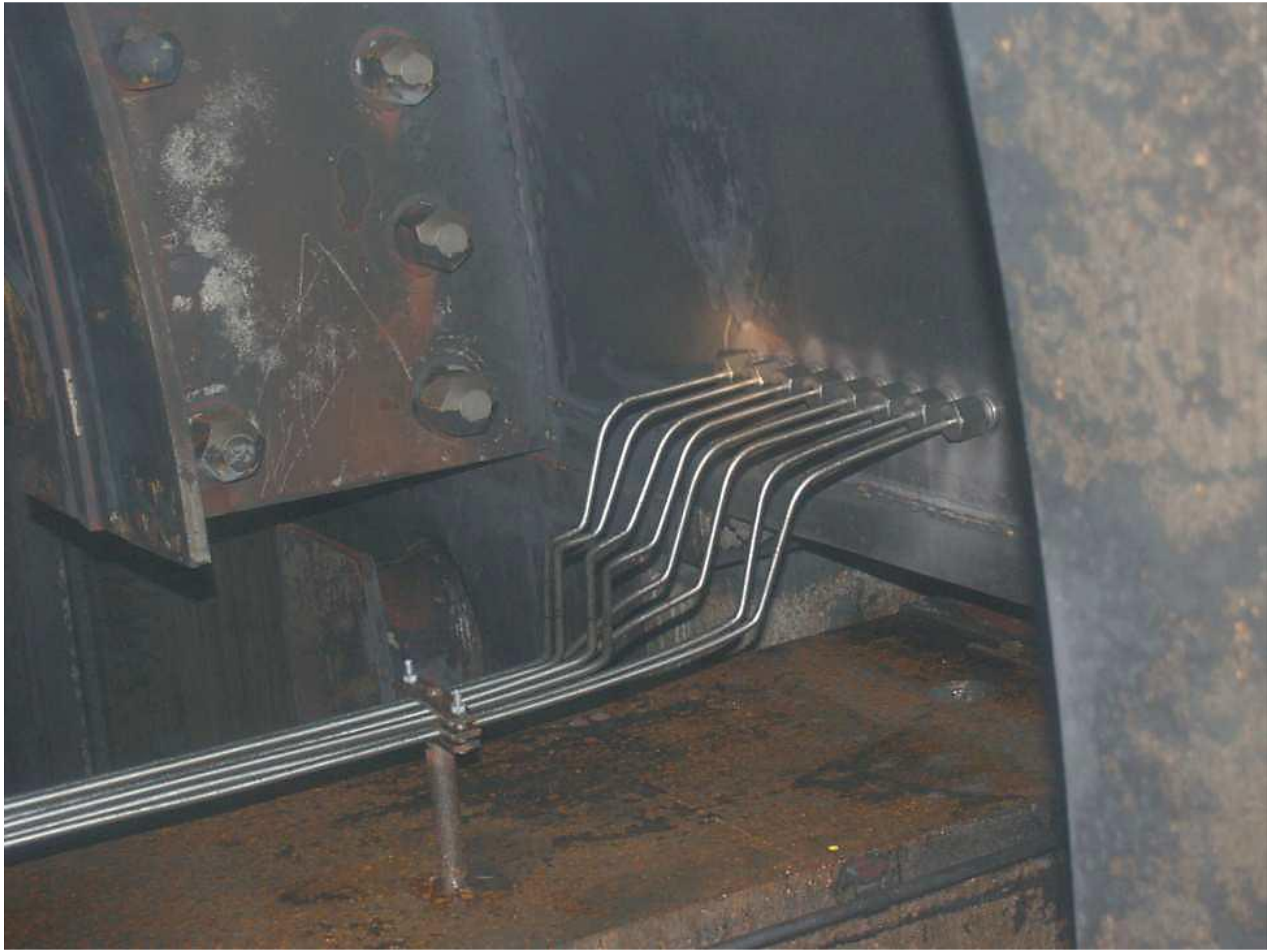
VMS Examples

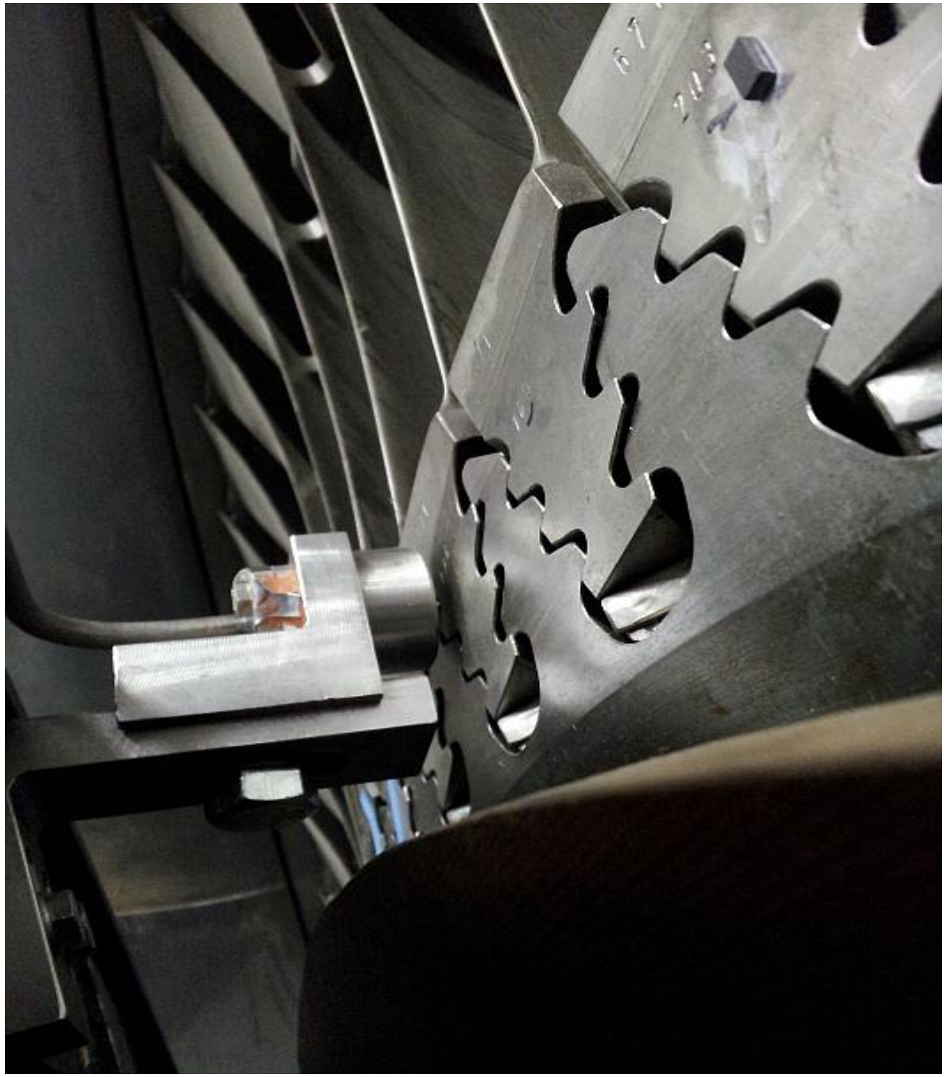
Sensor Installation in TG 300MW



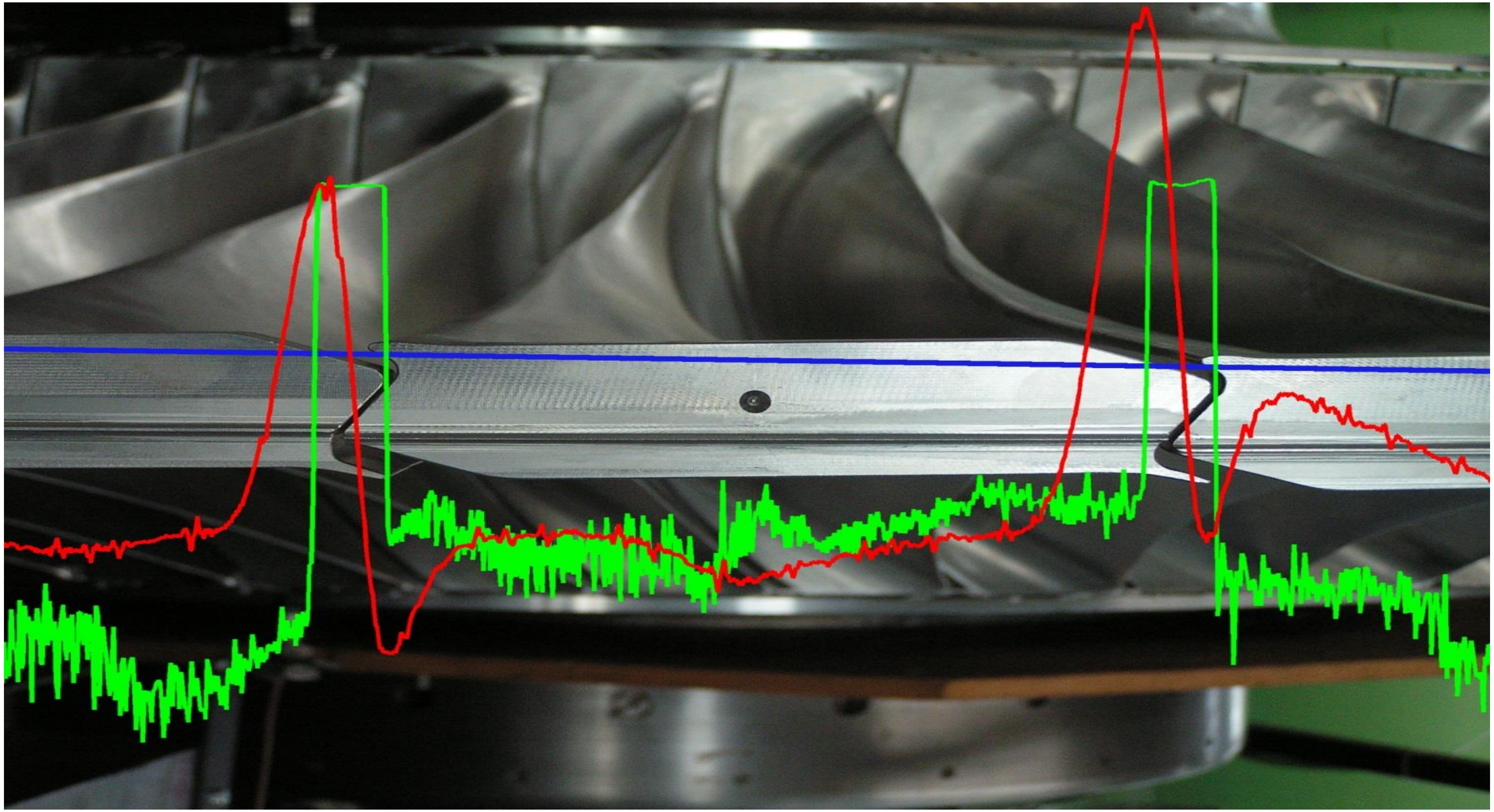
Sensor Installation in TG 1000MW



Installation of Blade Ejection Sensors



Blade Tip Sensing with Use of Optical and Inductive Probe

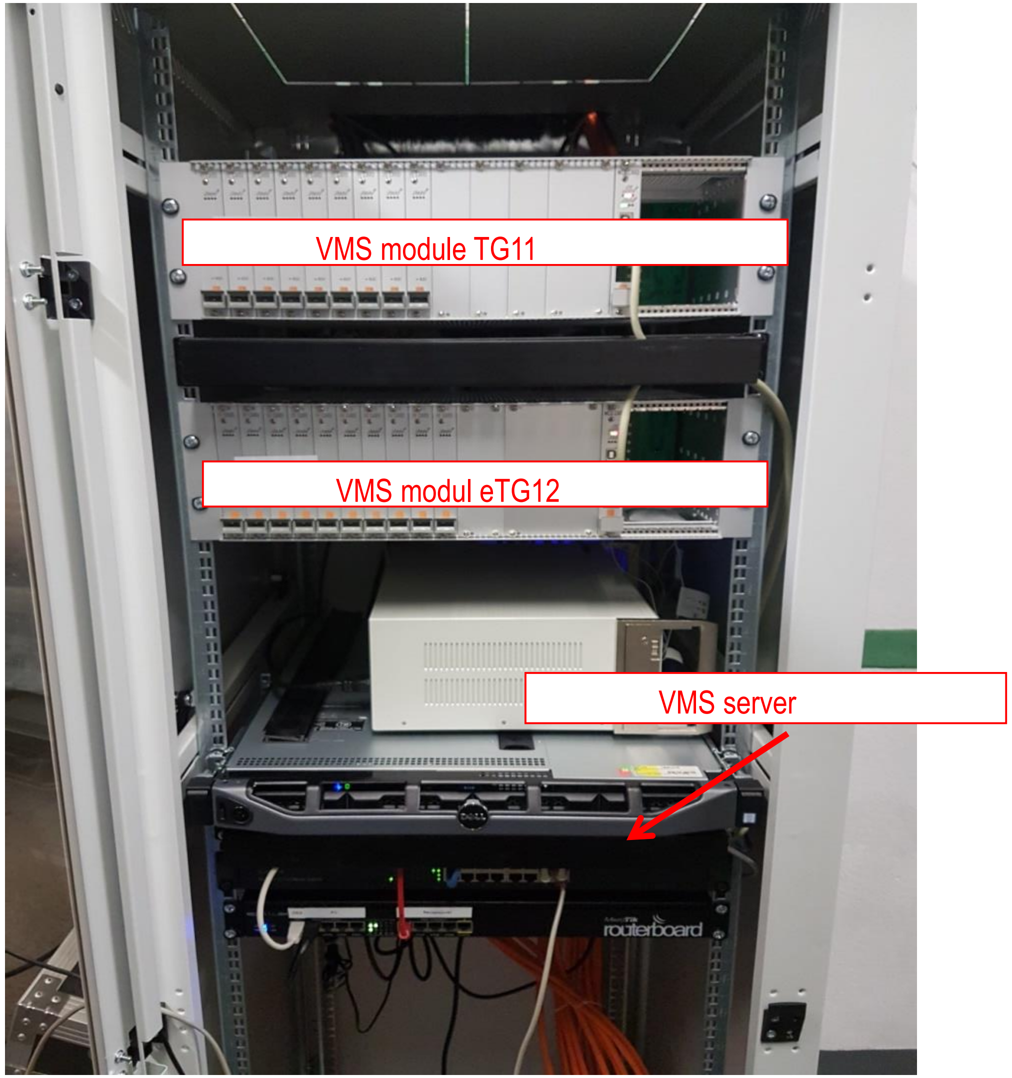


Line of measurement

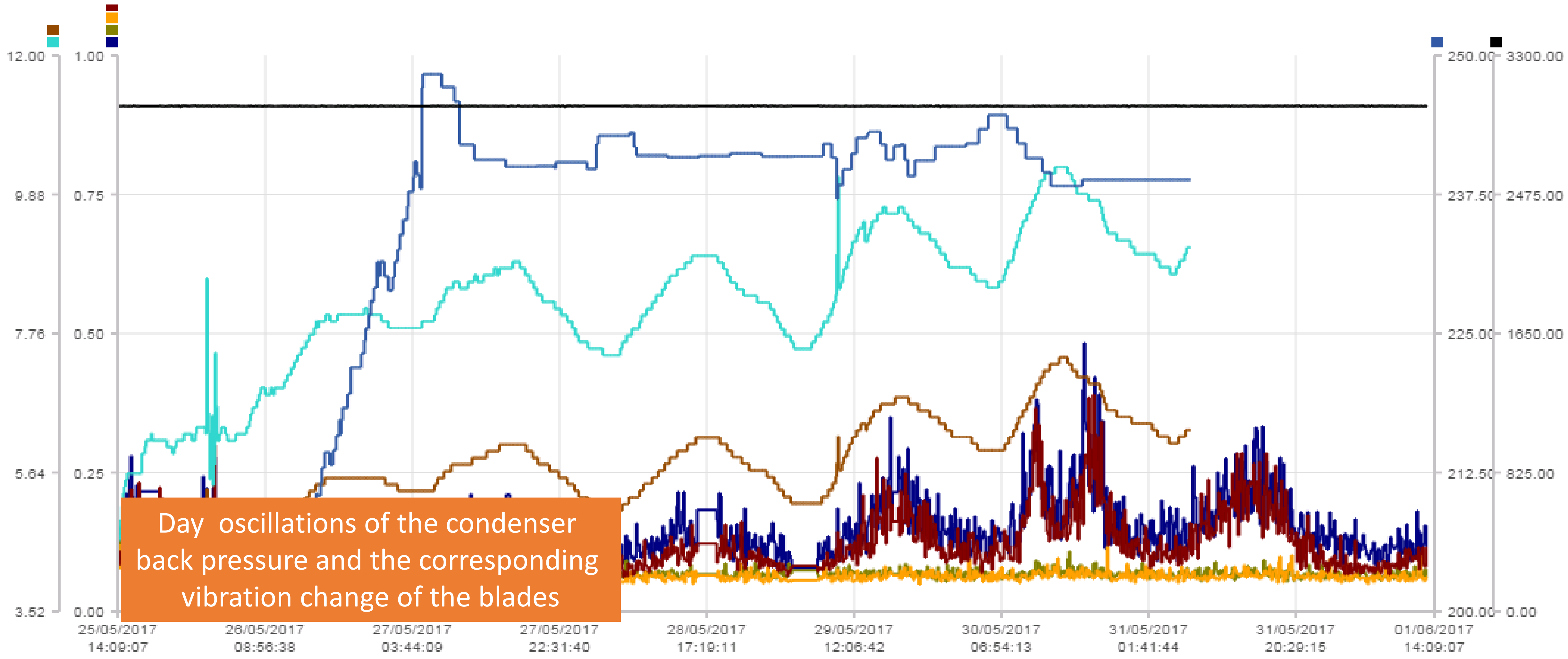
Inductive probe

Optical probe

VMS installation in NPP 500MW – 2 TG

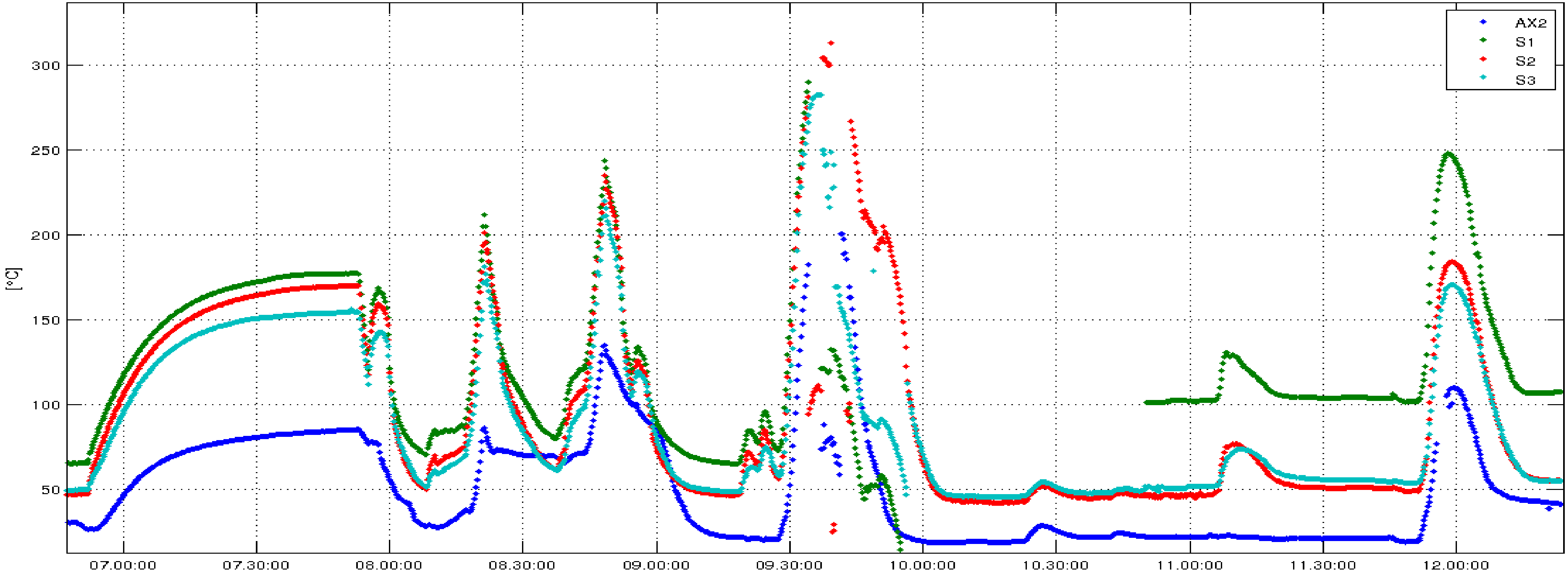


VMS – blade vibration versus TG load and condenser backpressure

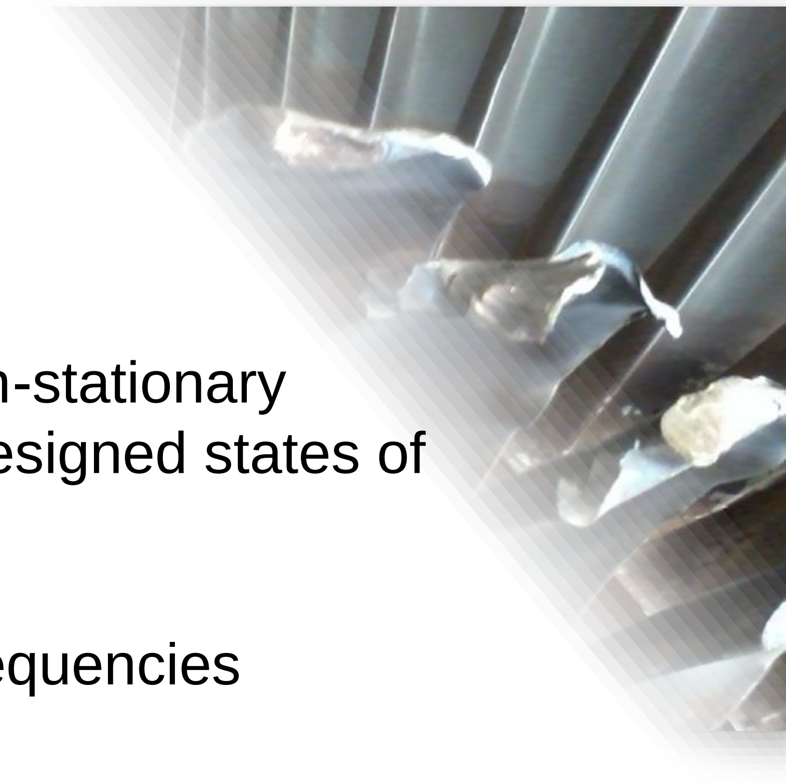


Day oscillations of the condenser back pressure and the corresponding vibration change of the blades

Temperature measurement during backpressure changes (measured with VMS-1901)



Why to use VMS system (BTT)



- Long-term monitoring of the blades in operation
- Instant information about vibration of individual blades
- Automatic capture of increased vibration of blades during non-stationary events eg. during TG phasing, instability of power grid, non-designed states of TG operation
- Trend monitoring of excited amplitudes and blade vibration frequencies leading to estimation of residual blade life
- Combined with other diagnostic systems, it is an irreplaceable source of information in the case of early detection of blade defects and subsequently for the analysis of the failure causes

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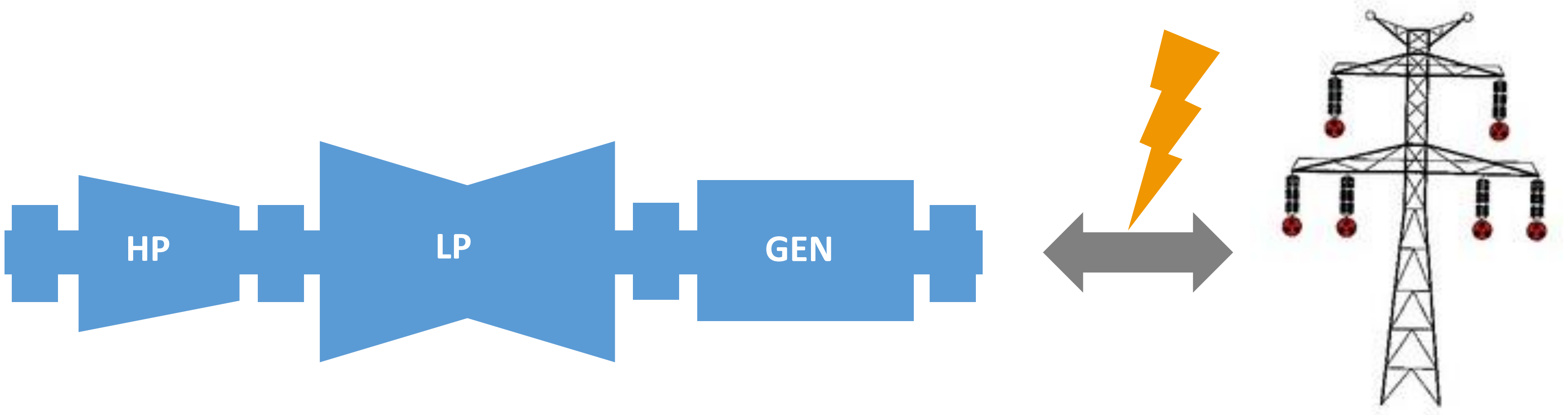
The measurement of the shaft torque and its impacts in operational cases

Introduction to Torsional Vibration

Typical torsional vibration

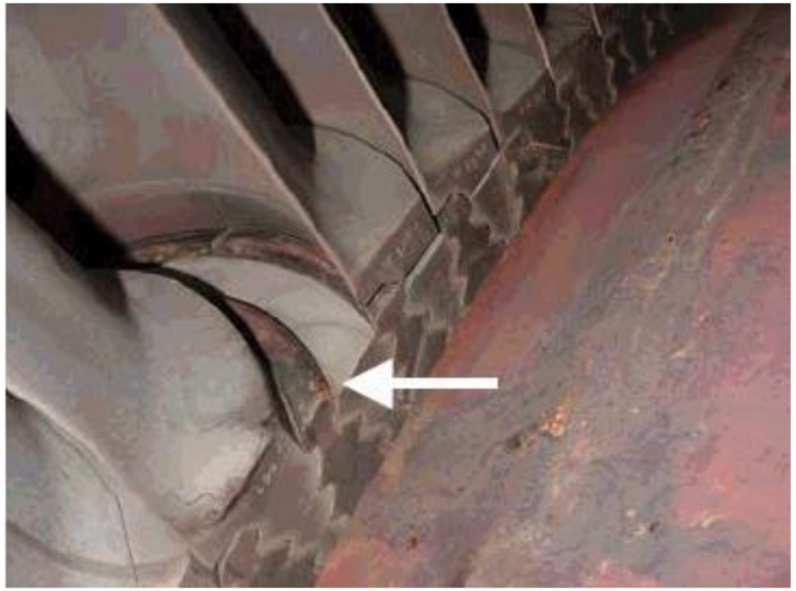


- Torsional vibrations are typically grid-induced
- Electro-magnetic field between rotor and stator couples shaft line to electrical grid

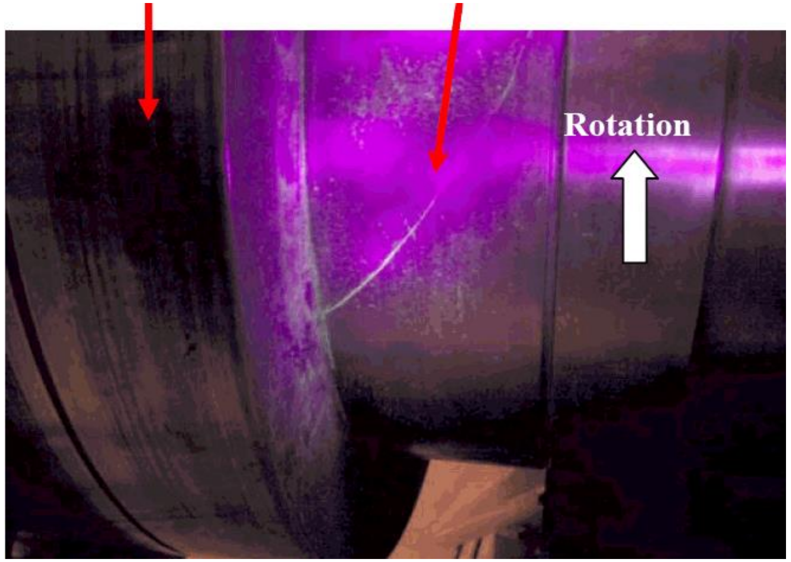
Introduction to Torsional Vibration

Different types of torsionally induced damage

- Fatique cracks at the root of LP turbine blades



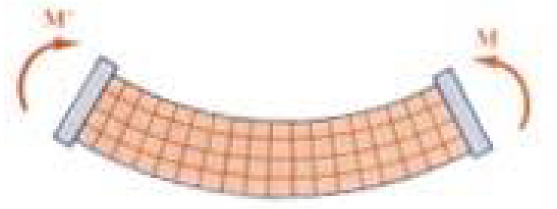
- Fatique cracks at high stress concentrations on the shaft



Introduction to Torsional Vibration

Lateral versus torsional vibrations

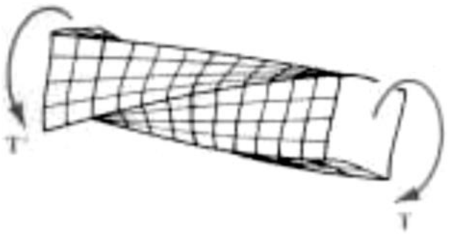
Lateral vibrations



- Horizontal/vertical vibration
- Usually sufficiently damped
- Internal excitation (unbalance)
- Excitation is implicitly in vibration measurement

- Standardly monitored
- Criteria/standards advanced
- Vibration is measurable even on the casing

Torsional vibrations



- Angular vibration
- Very lightly damped
- External excitation (grid)
- Extra detailed electrical measurement required

- Not yet standardly monitored
- No clear criteria/standards
- „Hidden“ vibration

Introduction to Torsional Vibration

Torsional vibration types of disturbances

ISO 22266 – **Mechanical vibration – Torsional vibration of rotating machinery** – Part 1: **Land-based steam and gas turbine generator sets in excess of 50 MW**

Types of disturbances	Step change	Excite at line frequency	Excite at twice line frequency	Excite at (between 0,1 and 0,9) of line frequency
Transient:				
Three phase fault	×	×		
Unbalanced fault[a]	×	×	×	
Synchronization out-of-phase	×	×		
Open transmission line (three phases)	×			
Close transmission line (three phases)	×	×		
Single pole switching	×		×	
Transient sub-synchronous resonance (SSR)				×
Disturbances in the grid due to thyristor controlled loads (e.g. variable speed electric motors)		×	×	
Steady-state:				
Line unbalance[b]			×	
Load unbalance[c]			×	
Steady-state sub-synchronous resonance (SSR)				×

a Unbalanced fault can be either line-to-line, line-to-ground or twice line to ground short circuits. Such faults can be seen either on the transmission system or more severely at the generator terminals.

b Line unbalance: Unbalance in transmission line or system, for example, untransposed transmission lines.

c Load unbalance: Unbalance of the electrical load of the system.

Introduction to Torsional Vibration

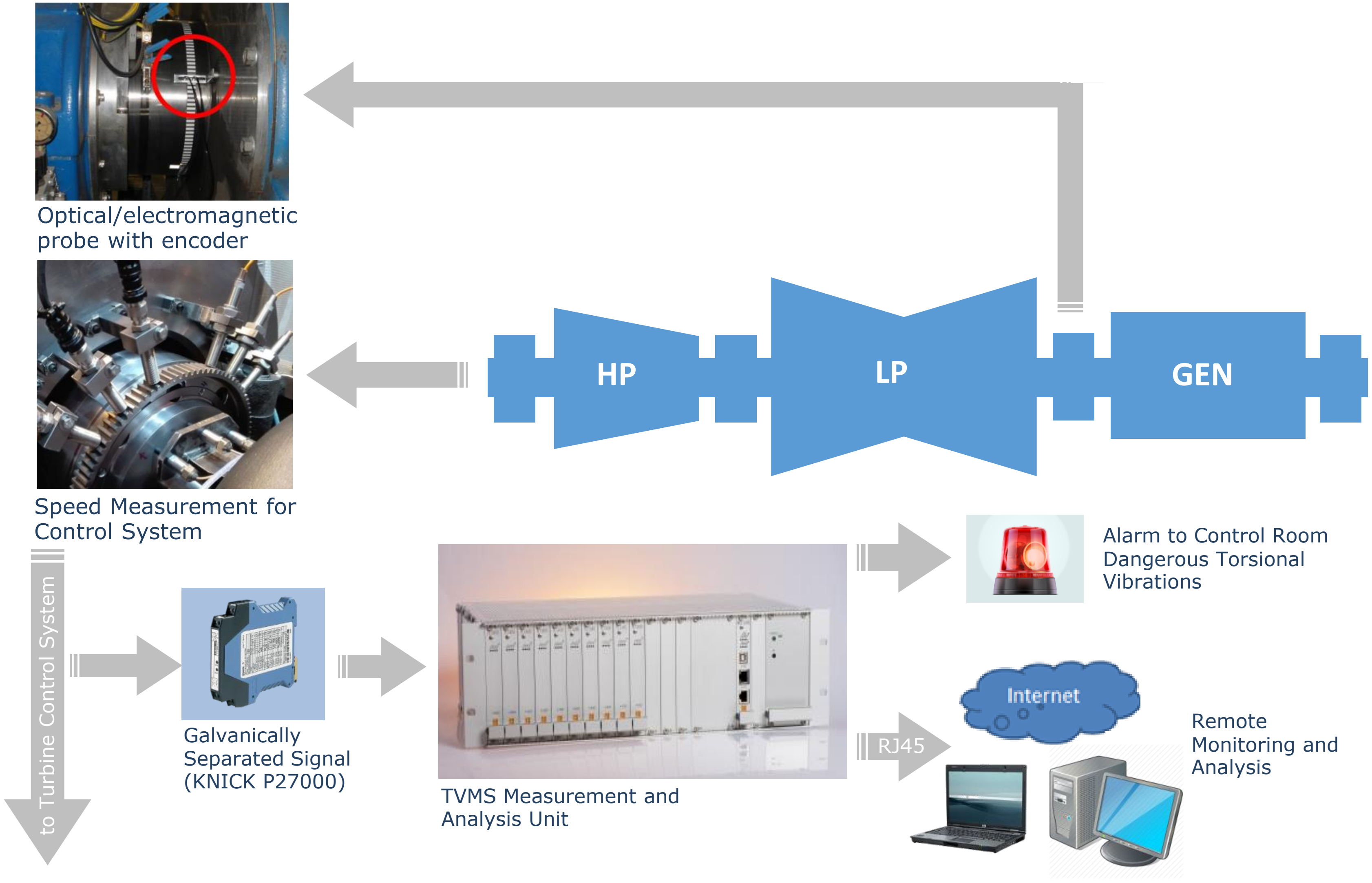
TVMS – Overview

Torsional Limits – TG Protection

Case Studies and References

TVMS – Torsional Vibration Monitoring System

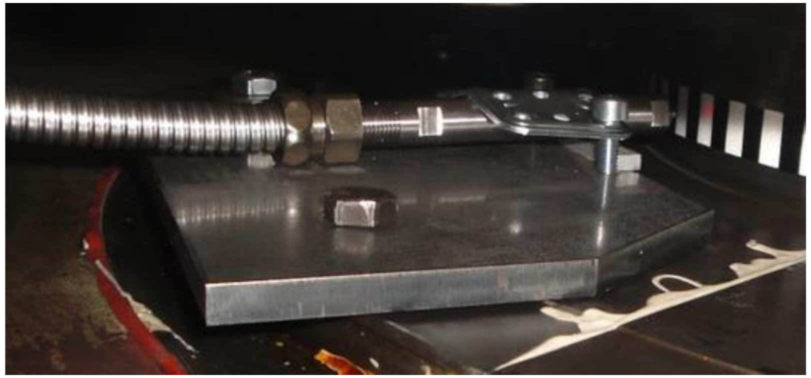
Solution Overview



TVMS – Torsional Vibration Monitoring System

Examples of sensor installation – Machine room

- Optical sensor with zebra encoder (multi-fiber probe measuring reflection from encoder)



Optical/electromagnetic probe with encoder

- Magnetic hall-effect sensor on a toothed wheel (one of the standard speed sensors or additive sensor is installed)

Speed Measurement for Control System

TVMS – Torsional Vibration Monitoring System

Solution Overview

- Flexible self-adhesive reflective zebra tape for use with optical sensors

- Flexible copper tape for use with eddy-current probes (fixing by high temperature epoxy)

TVMS – Torsional Vibration Monitoring System

Examples of the acquisition system – Instrumentation room

TVMS – Torsional Vibration Monitoring System

Examples of the acquisition system – Instrumentation room

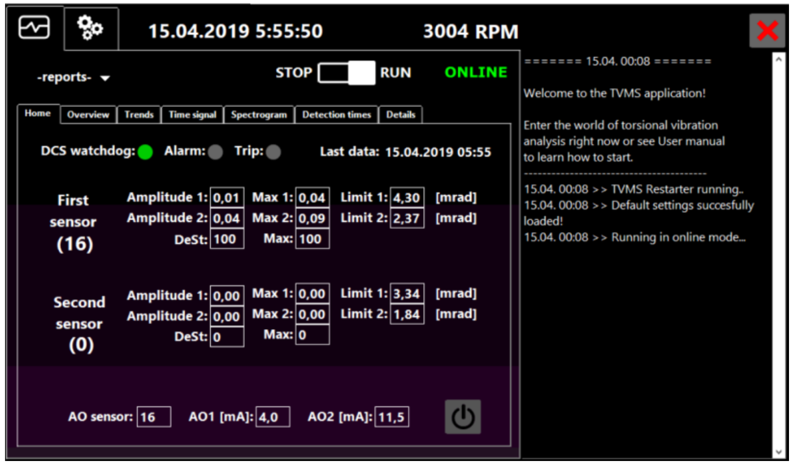
TVMS – Torsional Vibration Monitoring System

Post-processing Software

TVMS software properties:

- Different alarm types – transient events, amplitude trends
- Automatic storage of alarm events with predefined pre/post-trigger
- Data stored in DB for off-line Analysis
- Watchdog of HW/SW functionality to DCS
- Generation of Event alarms – connected to turbine protection

TVMS SW optimized for remote connection and monitoring



TVMS SW optimized for bulit-in or mobile display

Introduction to Torsional Vibration

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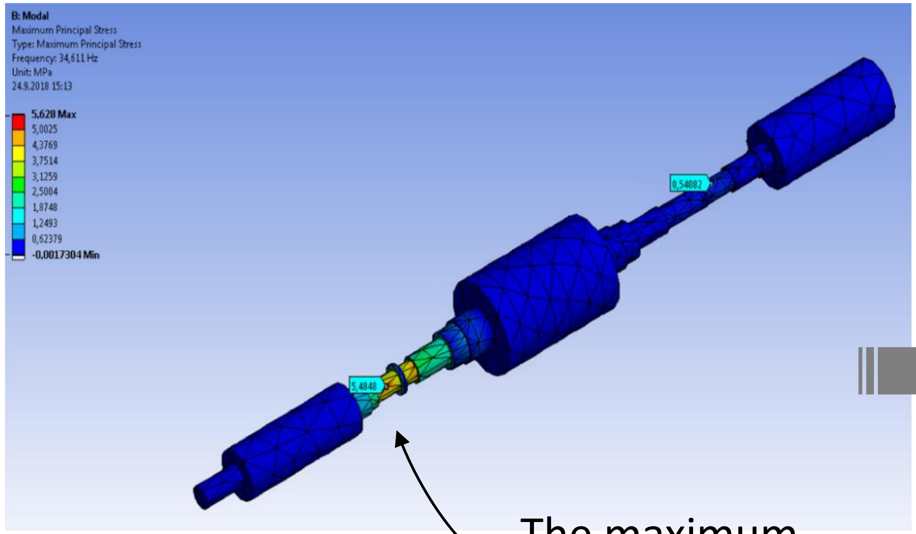
TVMS – Torsional Vibration Monitoring System

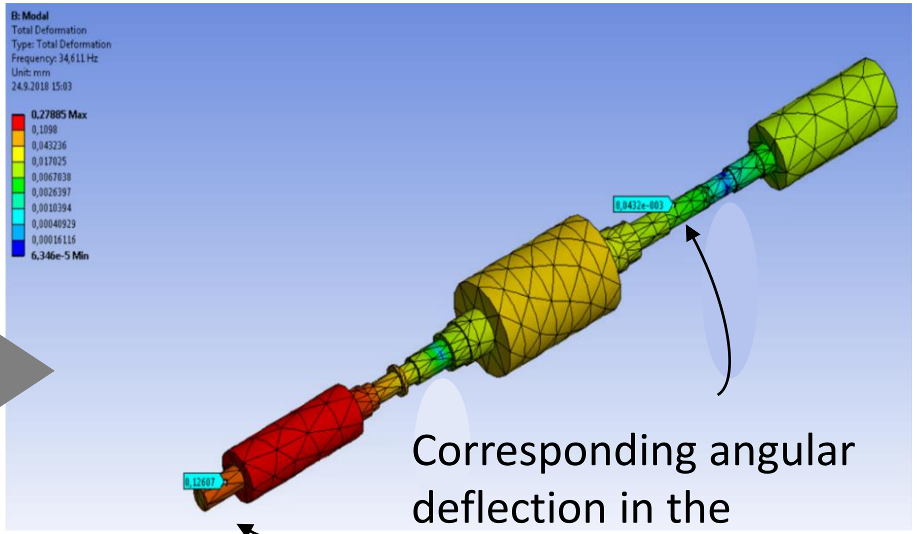
Torsional limits – TG protection

Finite element model:

- Determine local stress concentration
- Validate simplifications in torsional vibration model



The maximum allowable shear stress

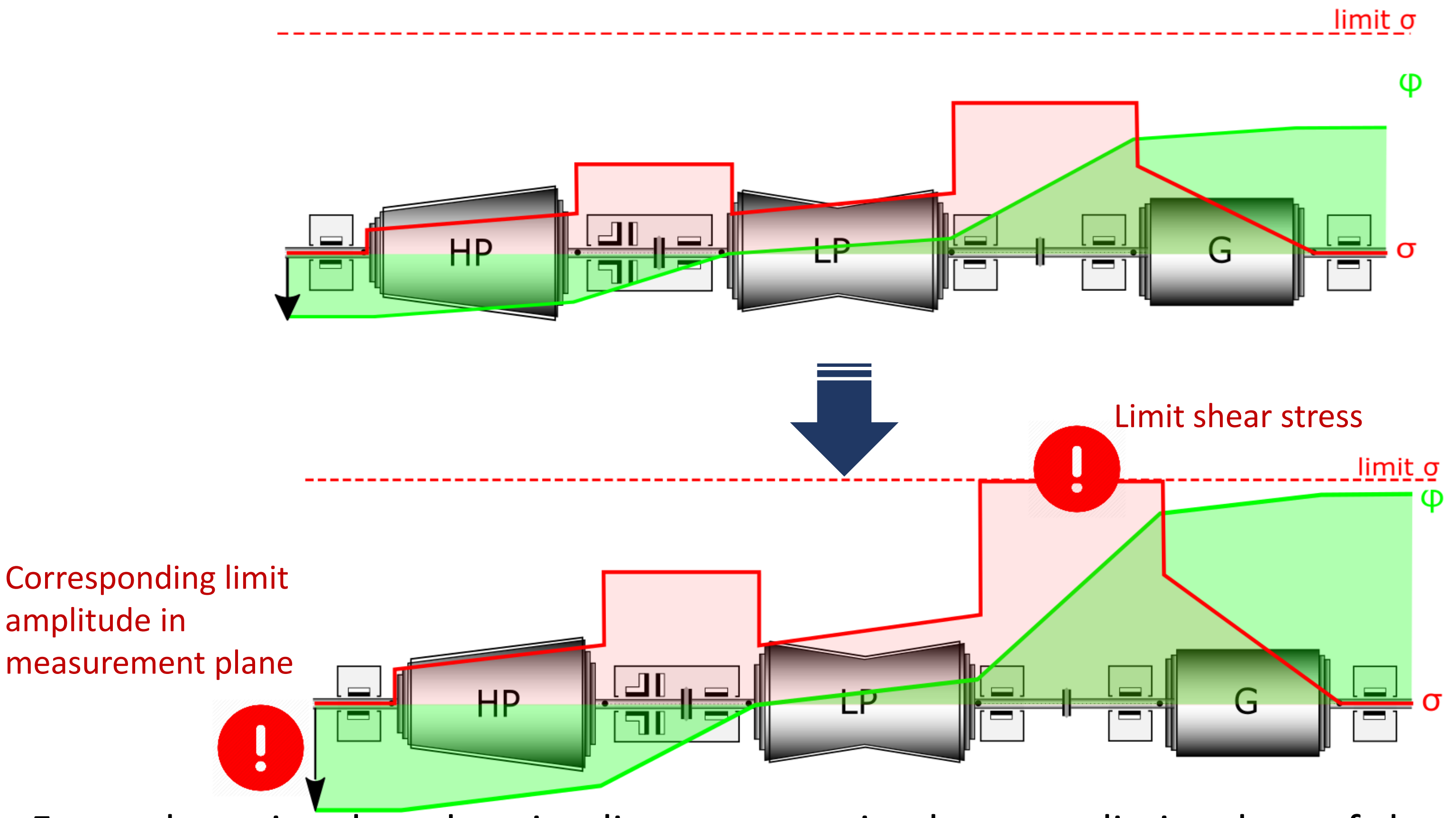


Corresponding angular deflection in the measurement planes

TVMS – Torsional Vibration Monitoring System

Torsional limits – TG protection

Torsional vibration model: Eigenfrequencies and mode shapes, Stress distribution



For each torsional mode exists linear conversion between limit values of shear stress and torsional amplitude in measurement plane

Introduction to Torsional Vibration

TVMS – Overview

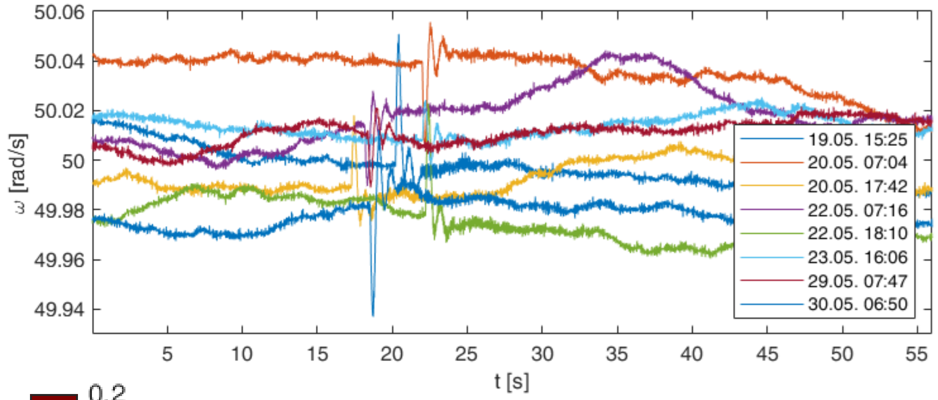
Torsional Limits – TG Protection

Case Studies and References

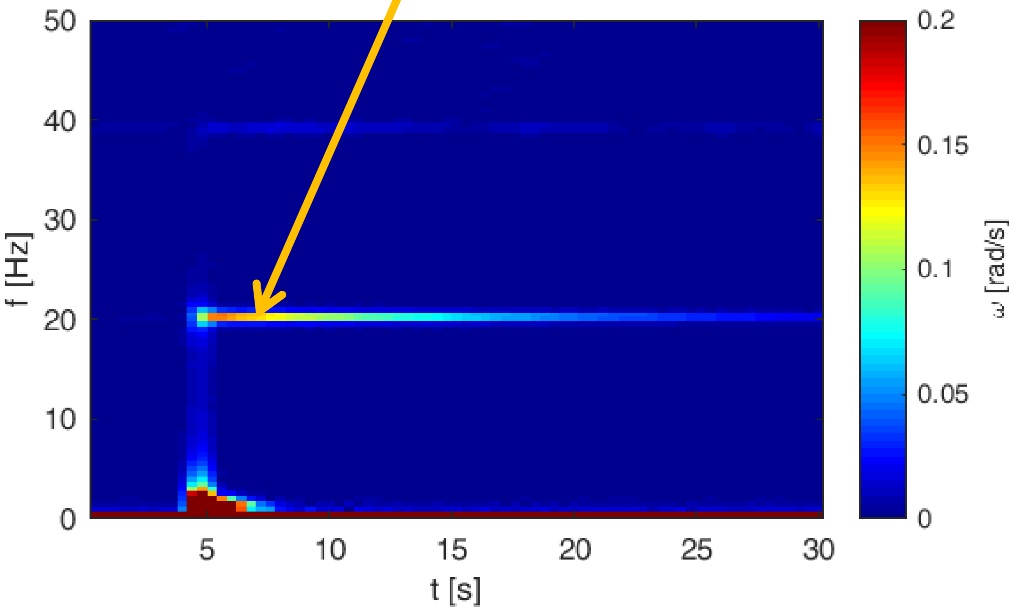
TVMS – Torsional Vibration Monitoring System

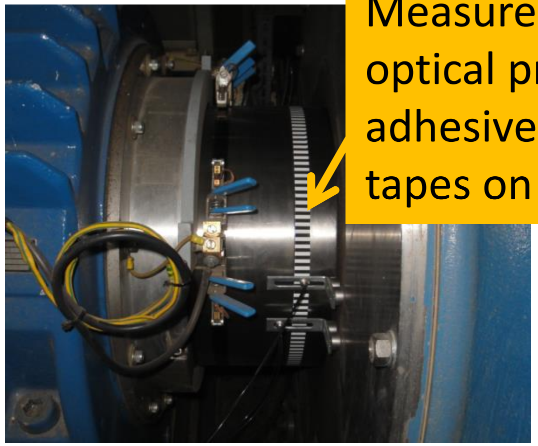
TG 250MW – electrical grid transients

Electrical grid transients due to line switching and grid events cause rapid changes in the generator air-gap torque and thus lead to rotor torsional excitation



First natural torsional frequency 20,2 Hz – peak amplitude is 120µm (0,54mrad)



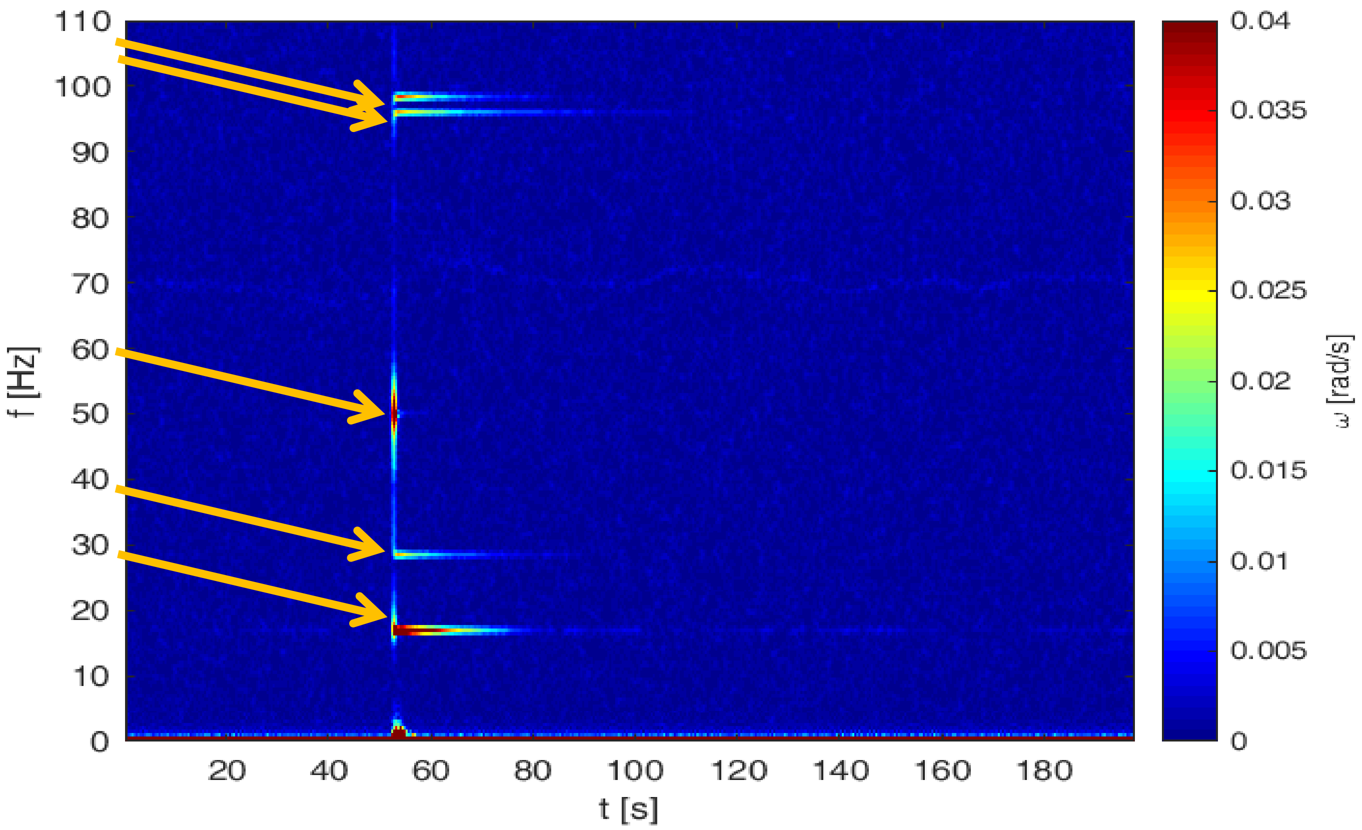


Measured using optical probes and adhesive zebra tapes on rotor

TVMS – Torsional Vibration Monitoring System

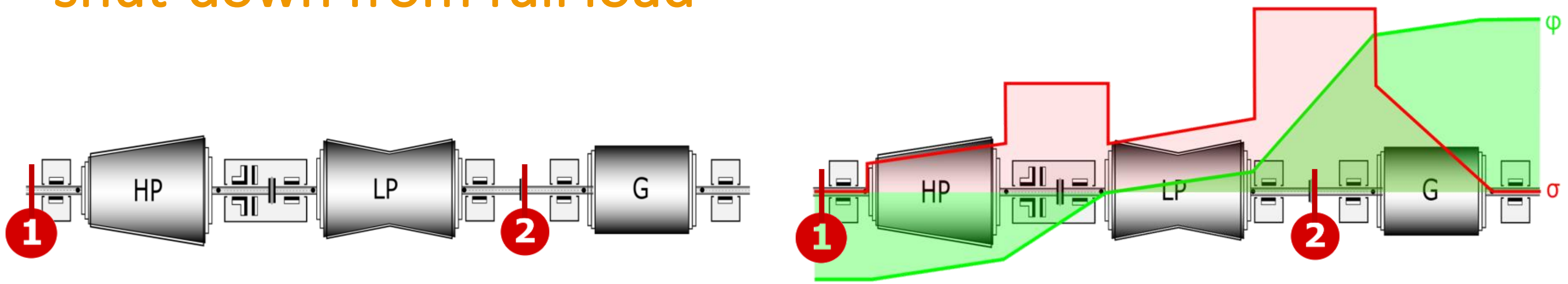
NOO 250MW – outage of a nearby TG

- During the measurement a sudden outage of a nearby unit occurred
- The torsional analysis approved excitation of 1st, 2nd and 3rd natural torsional frequency as well as the natural frequencies of the coupled shaft-blade vibration

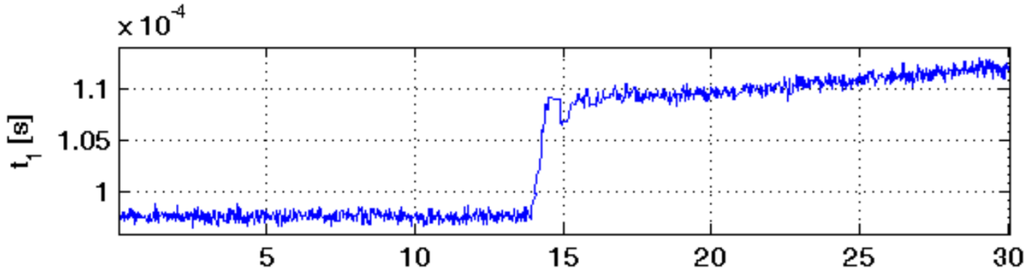


TVMS – Torsional Vibration Monitoring System

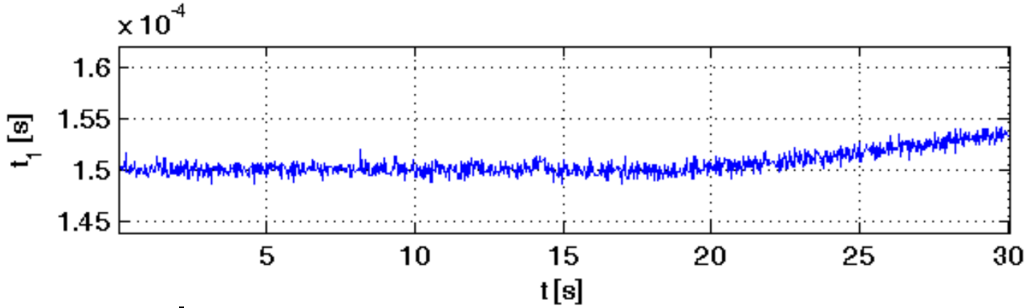
TG 250MW – shut-down from full load



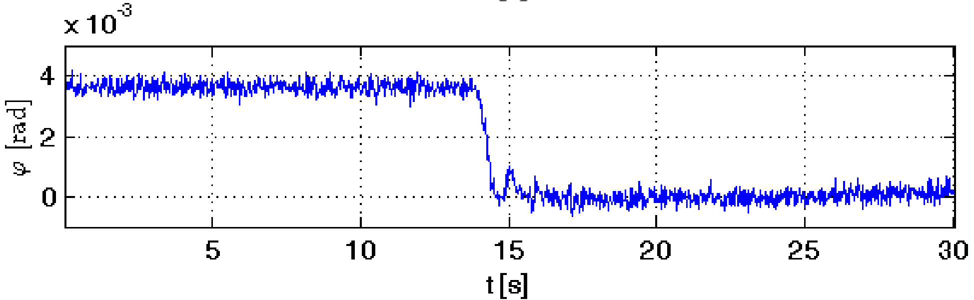
Sensor 1



Sensor 2

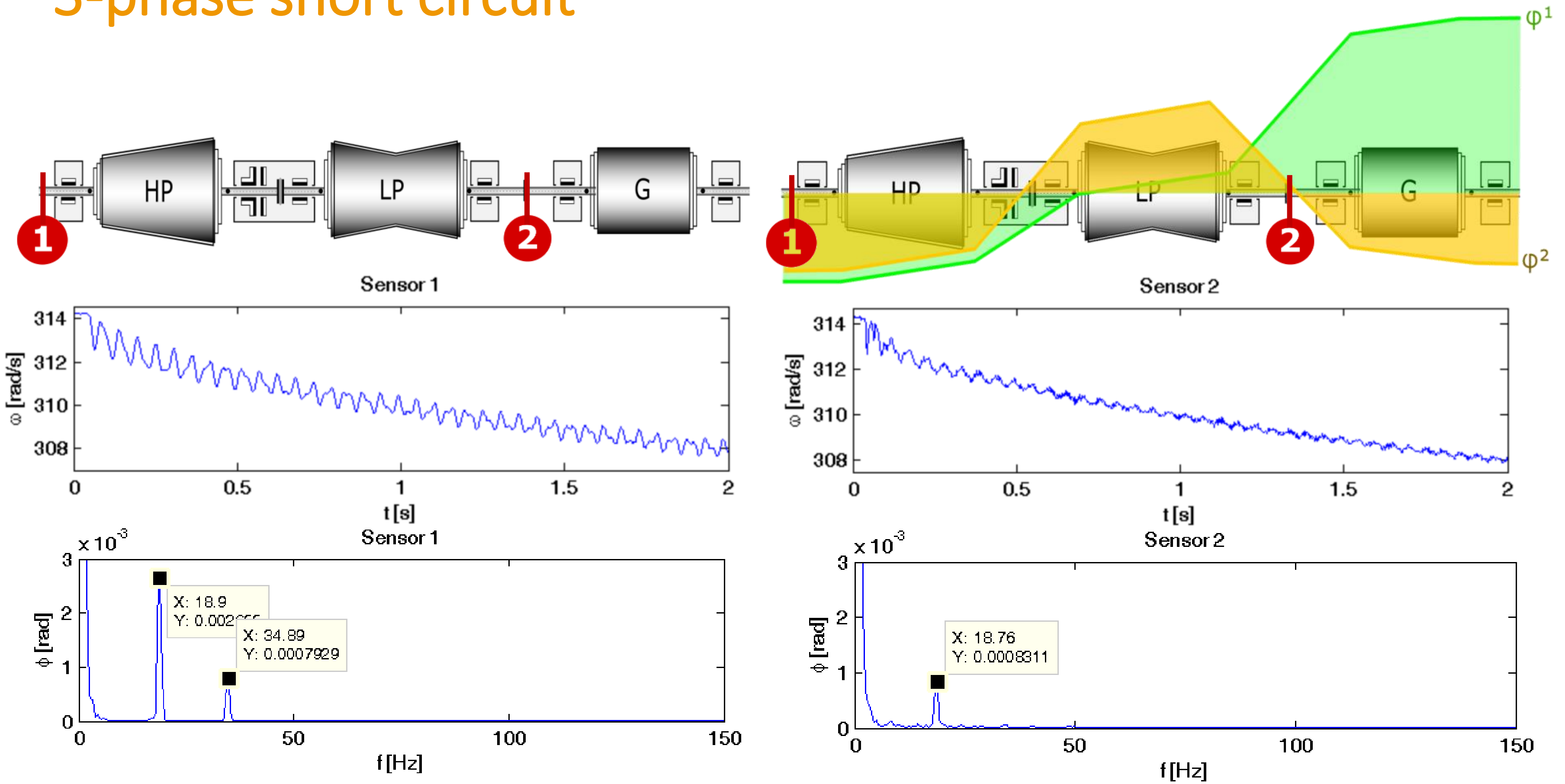


Twist between 2 1

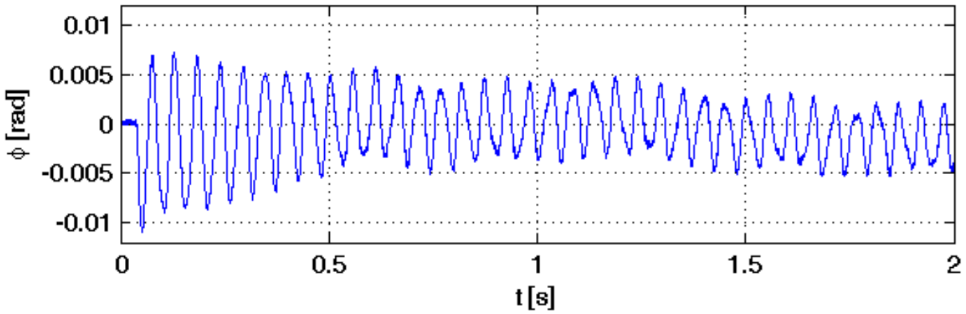


TVMS – Torsional Vibration Monitoring System

TG 360MW – 3-phase short circuit

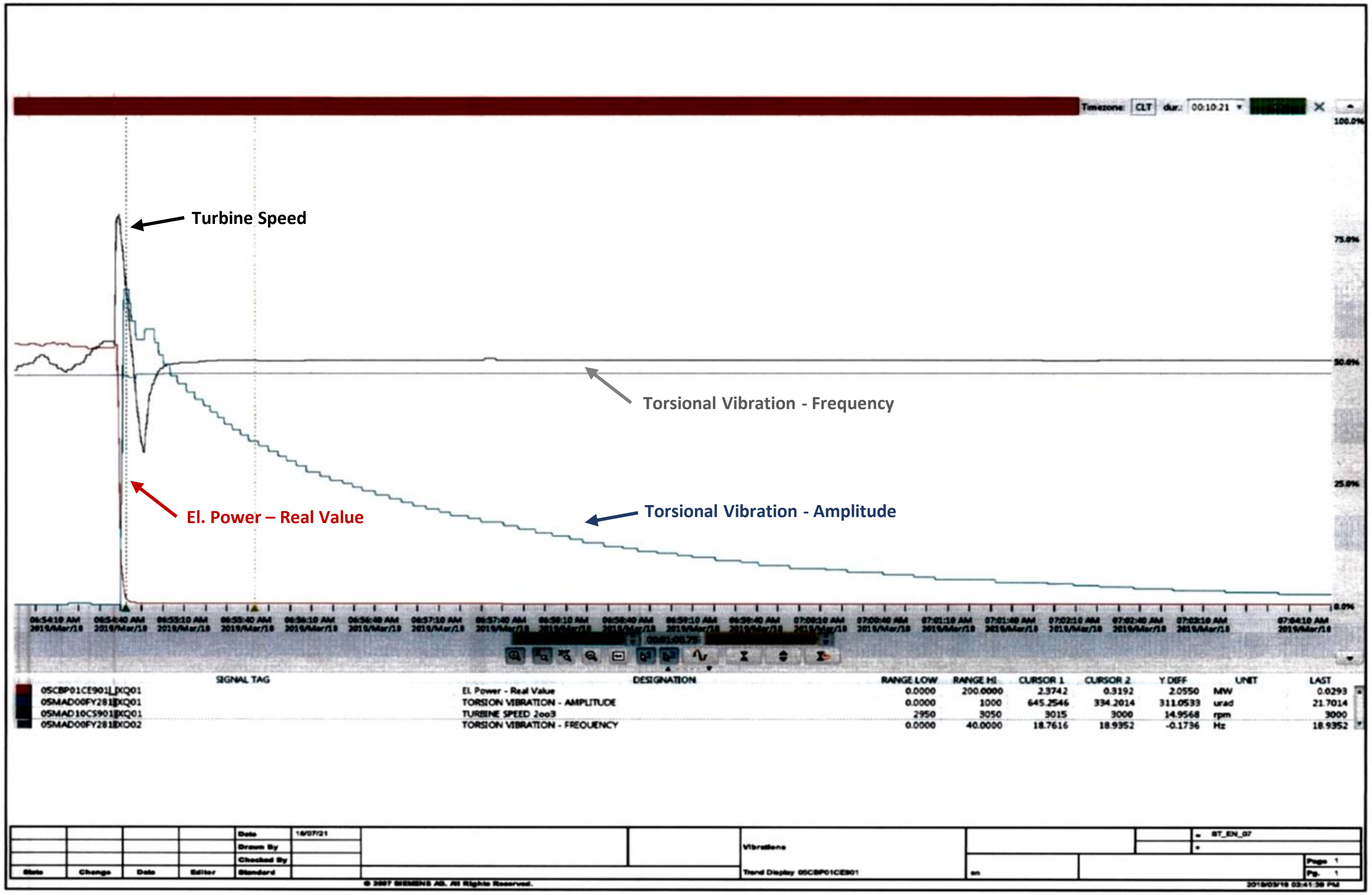


Twist between 2 1



TVMS – Torsional Vibration Monitoring System

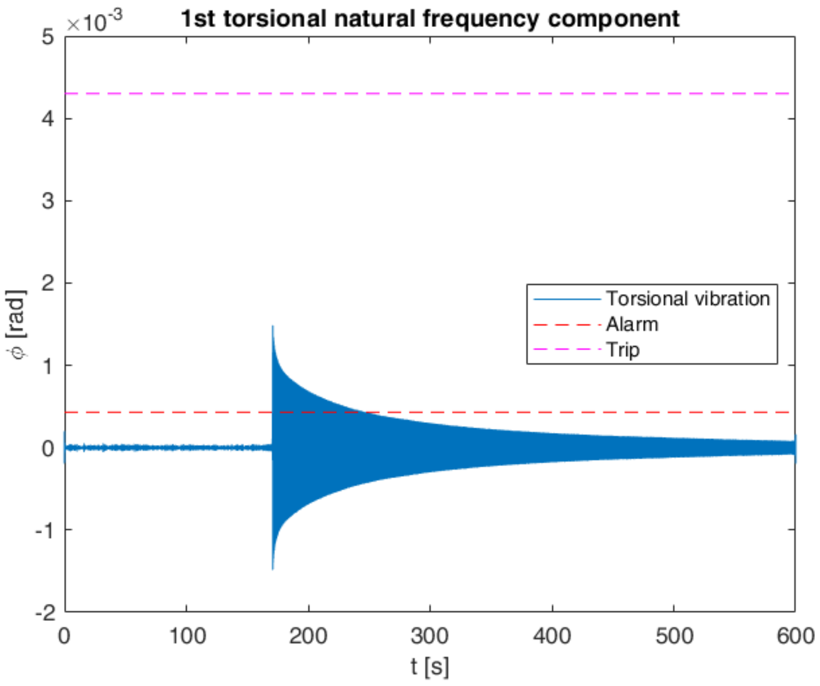
TG 360MW – trip test

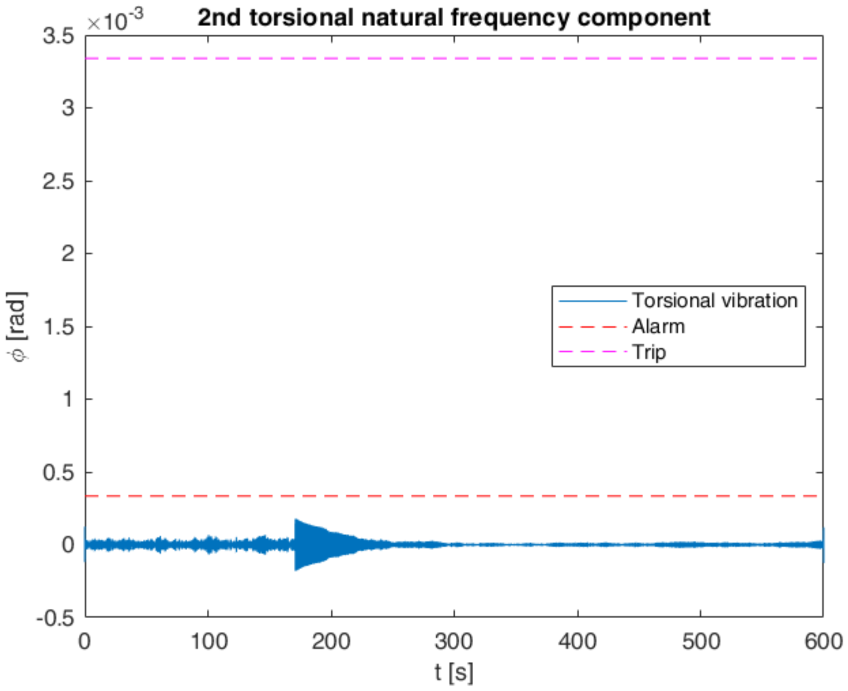


TVMS – Torsional Vibration Monitoring System

TG 360MW – trip test

- Damping of torsional vibration depends on actual rotor stress
- Torsional vibration fading is significantly longer than by lateral rotor vibration





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