APPLICATION NOTE

Vibration Diagnostics on a Turbo Generator Train

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Introduction

In order to guarantee sufficient production efficiency of plant assets and avoid unplanned downtime, investigating reasons for undesired turbine trips is key in chemical industries.

The case story describes here the study carried out to determine the root cause of a blade failure in a turbo-generator machine train. With that purpose, it is necessary to analyze machine vibrations with flexible and controlled tools providing all details of the rotor dynamics. Based on proximity probes, accelerometers, as well as other data such as rotating speed fluctuations, vibrations are carefully analyzed to obtain typical graphs allowing diagnosing the machine issues leading to blade vibrations and failure. In particular, the unexpected shape of the shaft centerline obtained after a machine run-up was studied to have a better understanding of the high-speed rotor behavior.

Finally, other typical turbomachinery tools and methodologies, such as torsional vibrations, ODS, end winding modal testing, sound intensity, and rotor balancing allowing to solve such problems are considered and described.

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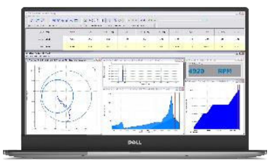
ORBIGate, Turbomachinery vibration software



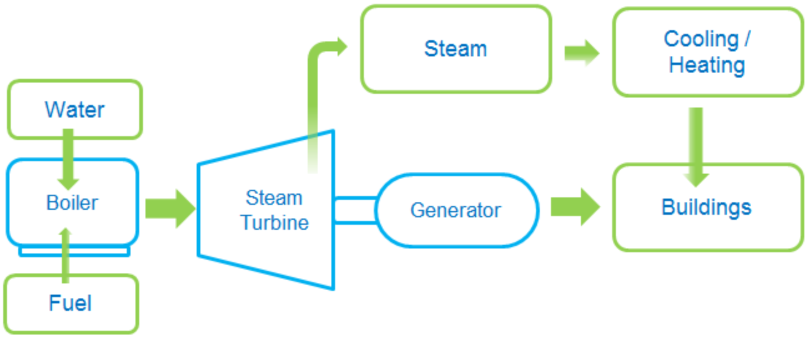
- Diagnostics tools: Scalar table, spectra; waterfall, Bode, Polar, orbit, shaft centerline, etc…
- User friendly set-up: designed by users for users
- Real-time acquisition of scalars and continuous time signal
- Post analysis and navigation

Mobi Pack, the ruggedized system

- Portable and rugged
- Datacare inside
- Direct Multiphysics sensor connection
- Embedded SSD drive for local time domain recording
- Built in battery

Machine and plant description

The machine train, a 15MW turbine generator group built in 1991, is for dual use in a waste water treatment plant. The organic materials issued from the treatment are burned to produce steam, and then generate electricity for supplying heat to neighborhood housing.

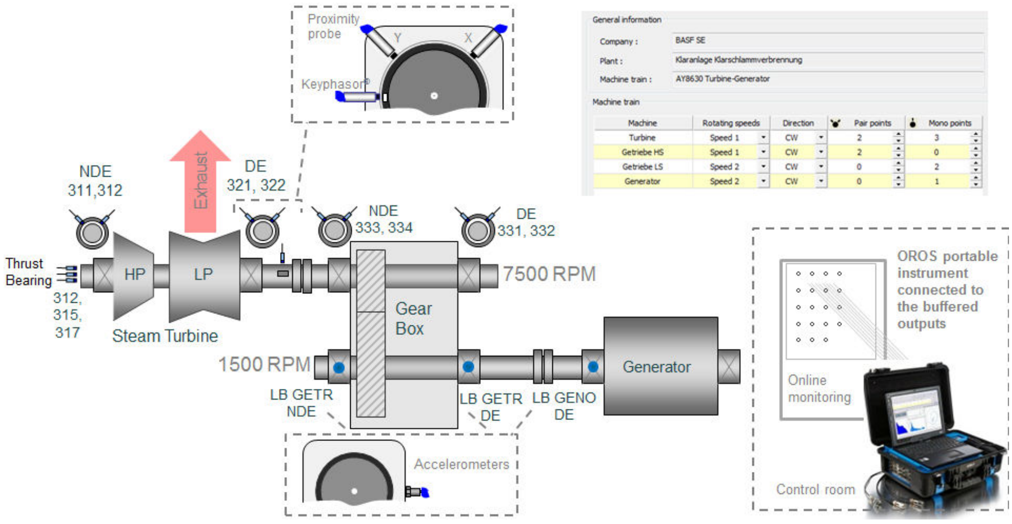


Simplified process flowchart

- High speed rotor (7500 RPM): a 1.5 ton steam turbine rotor flanged coupled to the gear box pinion shaft. The turning gear speed rotates the machine train at 180 RPM. No flexible coupling is used.
- Low speed rotor (1500 RPM): Bull gear shaft flanged to the 4 poles generator rotor (25 Hz).

Online monitoring system and sensors

- The high speed rotor is equipped with
  - 4 sets of radial proximity probes (eddy current sensors).
  - 3 axial proximity probes are mounted at the thrust bearing. It is a “2 out of 3 ratings” meaning that 2 of the 3 probes have to be above the trip conditions, avoiding unjustified trips.



Turbine generator machine train configuration and condition monitoring setup

- The low speed rotor is equipped with accelerometers to capture horizontal bearing housing (LB=Horizontal bearing housing). It is adapted to the low speeds and large masses of the generator rotor.

- The Keyphazor phase reference & rotating speed transducer is mounted on the high speed shaft. The phase reference & speed determination on the low speed shaft is achieved based on the gear ratio of the gear box.
- A single channel Torque sensor was used to investigate the torque fluctuations.
- Trip setpoint values are about 80 microns peak to peak (with time delay)

Events leading to the problem

- The steam turbine was a 20 year old machine and had operated during the entire time without any major issues.
- About a year ago, the machine was dismounted, shipped and overhauled, for upgrade and update purposes:
    - Erosion on the blades was noticed
    - Turbine controller was migrated and upgraded
    - The rotor was high-speed balanced on a high-speed machine.
- Back from overhaul, the machine was started up again.

Vibration and failure description

- Over the next 8 months the machine experienced several trips due to plant reasons (not necessarily for turbine reasons).
- After investigation, a crack was located on one of the blades in the exhaust region. This was unexpected.
- The turbine was opened again, the failure fixed, some modifications were introduced on the protection system and the machine was started again. From that stage, the machine ran normally. A root cause investigation was carried out to determine what could have been the reason for the initial blade failure.

Root cause investigation on the high speed shaft

The purpose of the test was to check that the turbine generator group was OK from a vibration standpoint. Various tests were carried out to determine what could have been the reason for the blade failure:

- Any Torsional vibrations? Consequently, the torque will be checked
- Is the speed regulator OK? Then the rotating speed stability will be checked.
- Is the Turbine NDE (Non drive end) average position OK? The shaft centerline position evolution should be checked.

A diagnostic system brought in to capture vibration data

- An OROS portable analyzer was used to collect more data than the online condition monitoring system and in order to perform thorough vibration diagnostics. The analysis carried out allowed the following data to be captured: nX vectors, Orbits and Shaft centerline, Bode plot, Polar diagram as shown in the figure below.

Typical tools and displays required for a thorough vibration diagnosis

- The OROS instrument acquires sensor signals through the buffered outputs of the online monitoring system: simple cable connections from the outputs to the analyzer's inputs. The instrument's +/- 40 volt inputs can accommodate normal sensor (eg, prox probe) voltages. The analyzer brings detailed vibration and torque diagnostic data that enables one to carry out a thorough diagnosis of the vibration situation.

- The instrument software, **ORBIGate**, is configured with the machine train details as shown below.

Machine	Pair label	Clearance	Direction	Orientation		Point label	Input
Turbine	Turbine.NDE		CW	45° L	Y	X41311 Y	2
				45° R	X	X41312 X	3
	Turbine.DE		CW	45° L	Y	X41321 Y	4
				45° R	X	X41322 X	5
	Mono point		CW	90° R		X41312	6
	Mono point		CW	90° R		X41315	7
	Mono point		CW	90° R		X41317	8
Getriebe HS	Getriebe HS.DE		CW	45° L	Y	X41331 Y	9
				45° R	X	X41332 X	10
	Getriebe HS.NDE		CW	45° L	Y	X41333 Y	11
				45° R	X	X41334 X	12
Getriebe LS	Mono point		CW	90° R		LB Getr DE	13
	Mono point		CW	90° R		LB Getr NDE	14
Generator	Mono point		CW	90° R		LB Geno DE	15

OK Cancel

Machine configuration

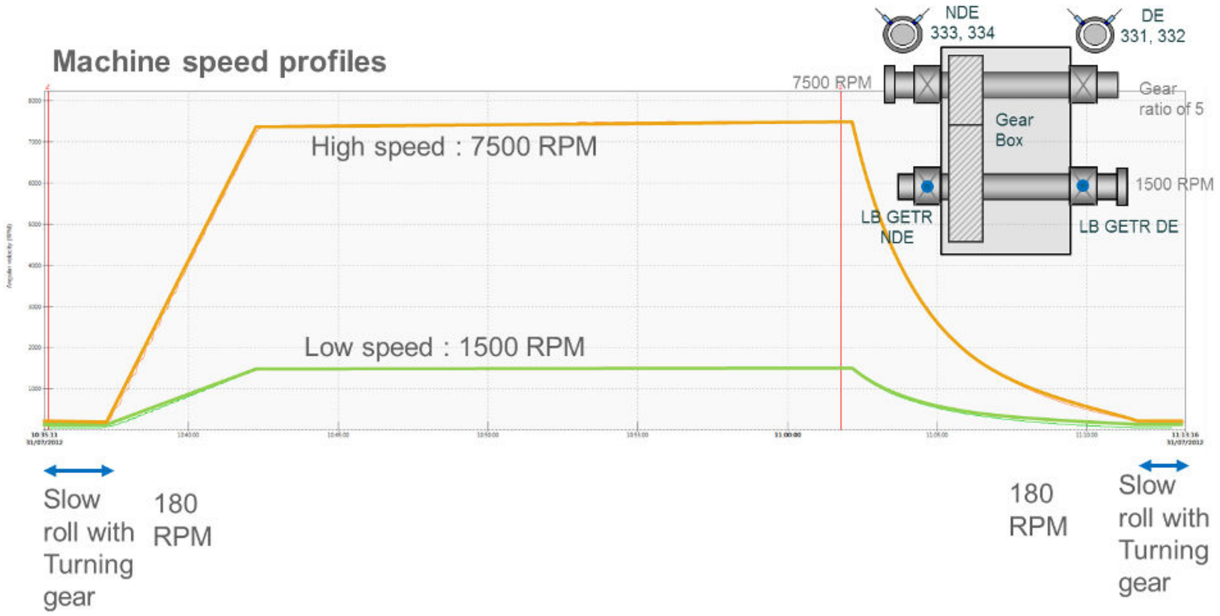
Inputs Filters

	Label	Transducer	Physical qty.	Sensitivity	Range pk	External (
Input 1	X41311 Y	Default Proximity probe	Displacement	8E-03 (V)/(µm)	1250 µm	1
Input 2	X41312 X	Default Proximity probe	Displacement	8E-03 (V)/(µm)	1250 µm	1
Input 3	X41321 Y	Default Proximity probe	Displacement	8E-03 (V)/(µm)	1250 µm	1
Input 4	X41322 X	Default Proximity probe	Displacement	8E-03 (V)/(µm)	1250 µm	1
Input 5	X41312	Default Proximity probe	Displacement	8E-03 (V)/(µm)	1250 µm	1
Input 6	X41315	Default Proximity probe	Displacement	8E-03 (V)/(µm)	1250 µm	1
Input 7	X41317	Default Proximity probe	Displacement	8E-03 (V)/(µm)	1250 µm	1
Input 8	X41331 Y	Default Proximity probe	Displacement	8E-03 (V)/(µm)	1250 µm	1
Input 9	X41332 X	Default Proximity probe	Displacement	8E-03 (V)/(µm)	1250 µm	1
Input 10	X41333 Y	Default Proximity probe	Displacement	8E-03 (V)/(µm)	1250 µm	1
Input 11	X41334 X	Default Proximity probe	Displacement	8E-03 (V)/(µm)	1250 µm	1
Input 12	LB Getr DE	Default Accelerometer	Acceleration	100 m(V)/(g)	100 g	1
Input 13	LB Getr NDE	Default Accelerometer	Acceleration	100 m(V)/(g)	100 g	1
Input 14	LB Geno DE	Default Accelerometer	Acceleration	100 m(V)/(g)	100 g	1

Instruments Inputs configuration

Speed stability

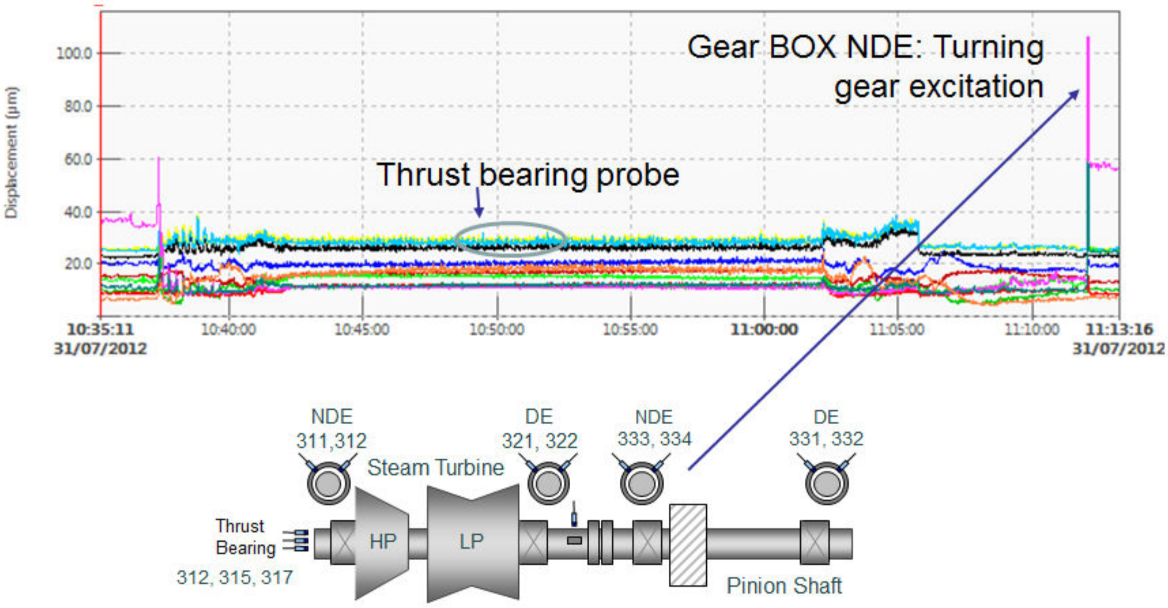
One Keyphasor, located on the high-speed shaft, allows capturing of the rotating speed's evolution. The speed of the low speed shaft is determined automatically based on the gear ratio (0.2) introduced in the software. The speed profile has shown that the speed evolution was stable and controlled. The speed instability doesn't appear to be a reason for the damaged blade.



High speed rotor (7500 rpm) and low speed rotor (1500 rpm)

High vibration level during slow roll: turning gear excitation

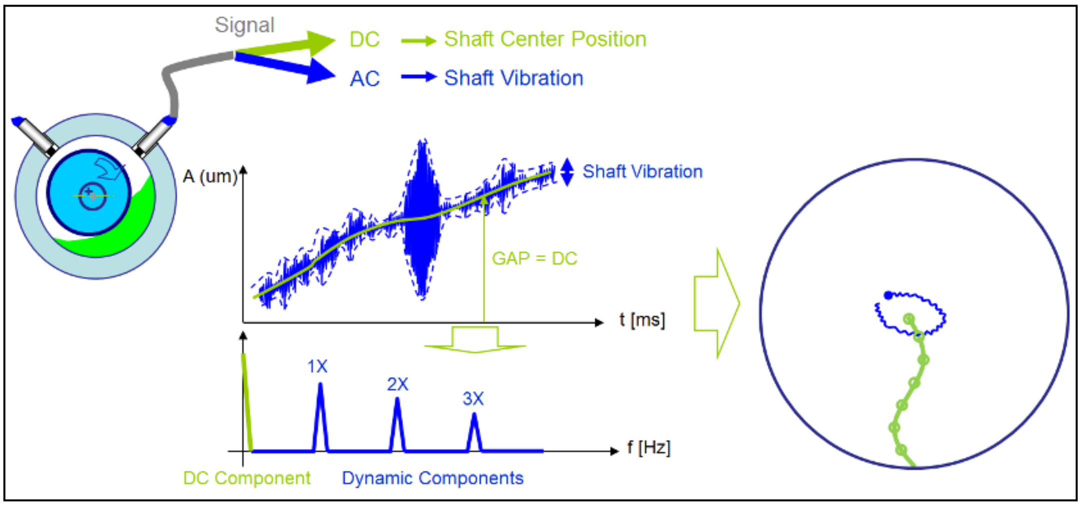
A high vibration level with a peak was experienced during slow roll (180 RPM). At first glance, this could be thought to be mechanical or electrical runout. But it is not. This is due to a relatively large eccentricity between the turning gear and the turbine rotor. The vibration drops when the turning gear gets uncoupled with a peak at that particular moment. The machine doesn't trip thanks to a time delay set-up. The runout was determined to be 5 to 7 microns peak to peak, which is considered to be standard.



Low speed turning gear related vibrations on the high speed shaft

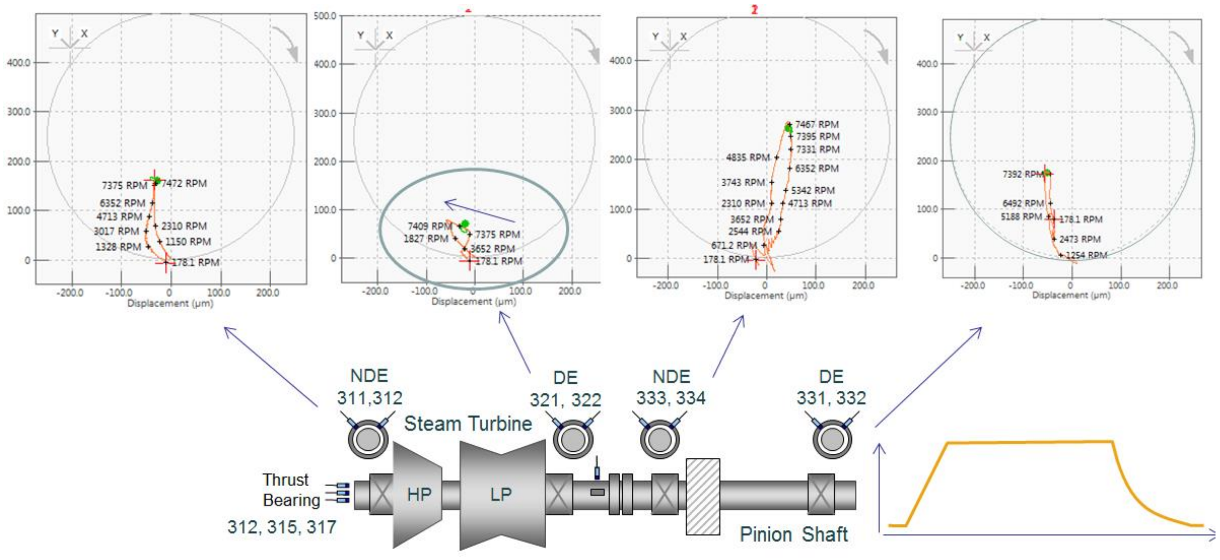
Full Shaft Motion of the pinion shaft rotor line: Gap and orbit measurement

The shaft centerline is a key feature dedicated to the display of the position and motion of the center of the shaft at each bearing. This is achieved by collecting the DC component of the signal for each probe. Adding the Orbit and the clearance circle to the display, the Full Shaft Motion is obtained.



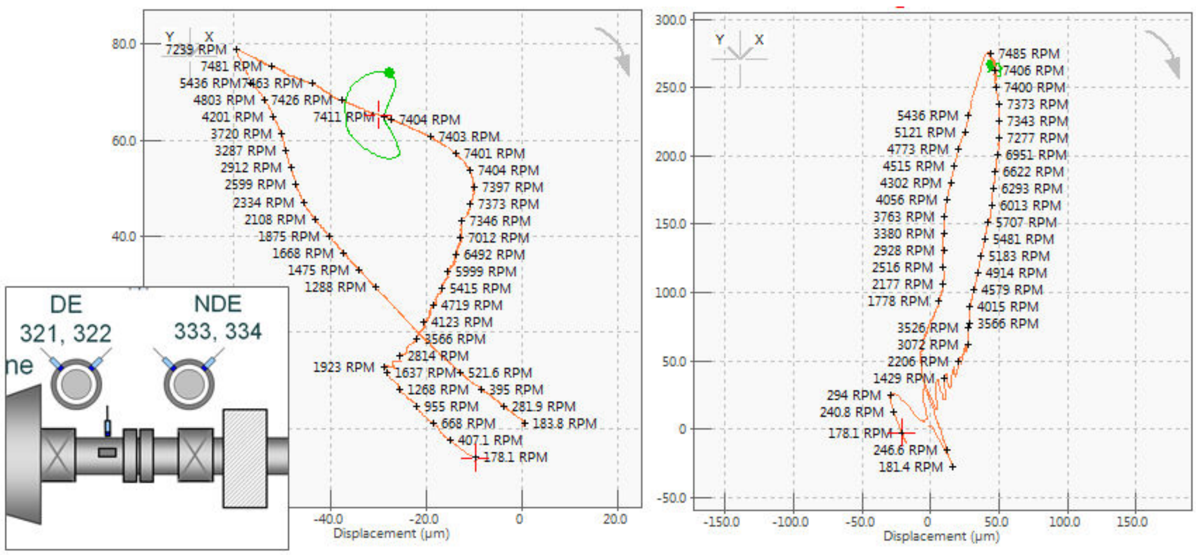
Collecting AC and DC components to display the Full Shaft Motion

In the case of the studied rotor, the bearing clearance is 250 microns. This value is set in the software to display the clearance circle.
The turbine rotor and gear box Non Drive End (NDE) proximity probe readings show a displacement of the rotor. It is due to small loads and successive openings of several inlet valves.



High speed rotor shaft centerline (Gap and Orbit)

One can see an evolution of the shaft centerline position. It is due to the sequence of the valve openings. The orbit size could show that the vibration was not relevant. It is often an interesting display to follow at the NDE of the pinion shaft. The shaft centerline was considered to move normally.



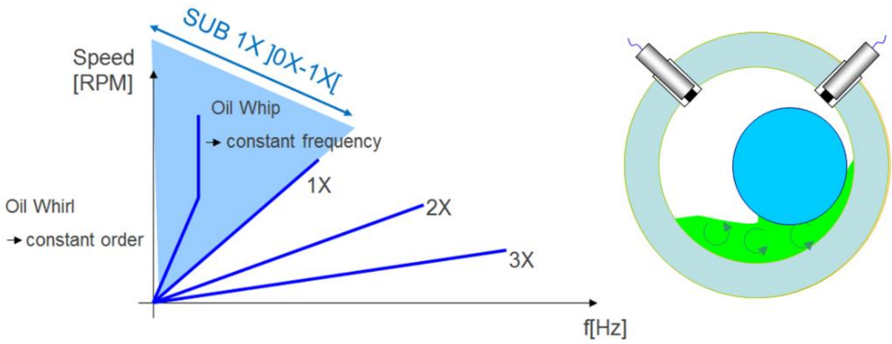
Full shaft motion (gap & orbit) at the turbine drive end

Resonance at critical speed

The machine was recently overhauled and balanced. Consequently it was checked that no critical or resonance would be experienced. The vibration levels are pretty stable in their evolutions with the rotating speed.

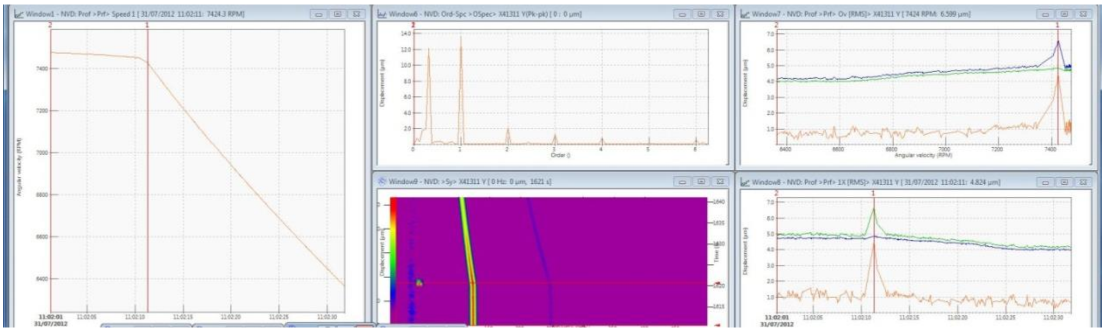
Subsynchronous instability

Oil whirl appears during a short time possibly due to the uncoupling of the generator. This can be evaluated thanks to the SUB1X criteria that capture the RMS vibration value between the DC and the 1X order line.



SUB 1X parameter to detect subharmonic oil instability

Rotordynamic calculations decrease the risk for subsynchronous instabilities. It can happen even with wornout tiltpad bearings as it can prevent the pads to tilt properly.



Sub 1X indicator to locate subsynchronous instability

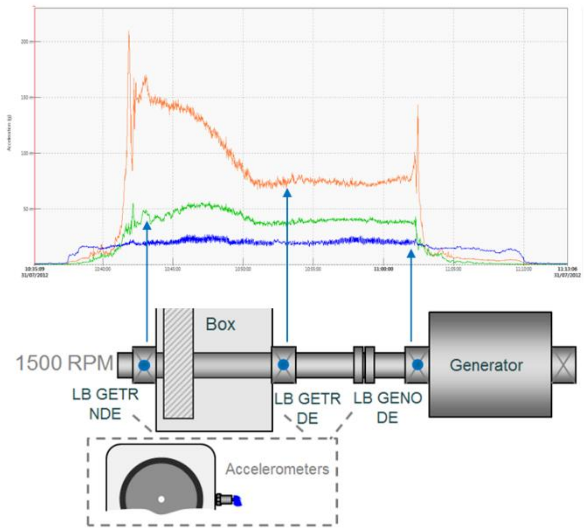
Torque measurements

Voltage output could be read on the analyzer and correlated to the Torque. No special behavior was visible. Alternative approaches exist for torque measurements: Telemetry systems, Torquemeter dual tach probe. With the technique used, and looking at the plots obtained, no Torsional frequency could be detected.

Torque sensor used during the test

Low speed shaft analysis: horizontal vibrations

An investigation was carried out as well on the generator low speed rotor. The result is shown in the figure below.



Acceleration acquisition on the low speed rotor

Blade failure conclusions

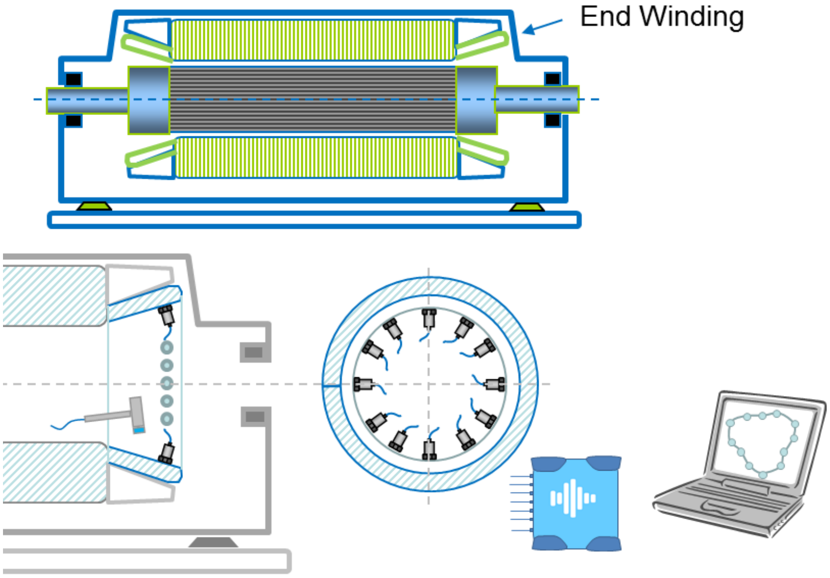
Based on the wealth of data from the OROS instruments, a number of tools such as SUB1X, shaft centerline, and torque measurements were used to be able to confirm the root cause of the blade failure. After investigations, the speed regulator shows no particular problems. No torsional resonance frequency appears. **At the end it was found out that the blade excitation and damage was most probably due to an excessive steam extraction through the exhaust system. It can be linked directly to the ventilation in the low pressure casing.**

Other field measurement techiques applicable on turbine generators

Other measurement techniques can be used on the field to investigate noise and vibration issues on turbine generator machine trains. It was mentioned earlier that the OROS instrument can connect to the sensors via the online monitoring system. In addition to that, it can, as well, connect directly to the sensors (piezoelectric accelerometers, impact hammers, pressure sensors, strain gage, temperature, microphones etc…) making it a versatile field diagnostic system.

End winding modal tests

Typically, generators experience high excitation at twice the network frequency. During each acceptance test, typically after rewinding, a modal test is carried out to check that no resonance is existing at those frequencies. For that test, 16 accelerometer channels are used as well as one hammer channel as displayed on the figure below.



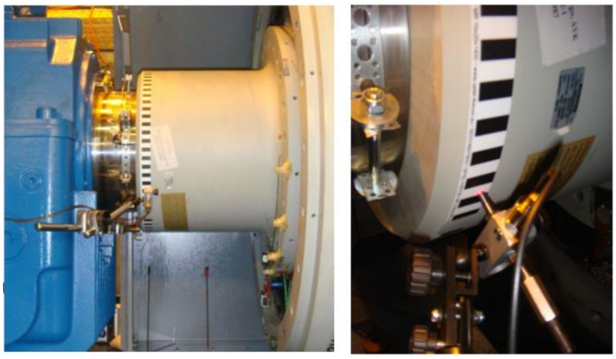
End winding impact hammer test

Thanks to ICP conditioning, both impact hammers and accelerometers can be connected directly to the analyzer without any additional conditioning or cables required.

Torsion and torque measurements

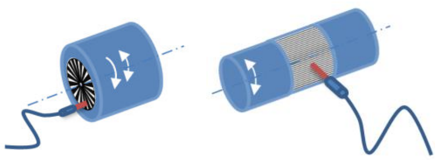
During the above case study, an inductive torque sensor was used. Other techniques are used on the field to measure torsional vibrations and torque. Each of them has advantages and drawbacks:

- Laser: Non contact technique so easy to setup. Typically used at fixed RPM
- Strain gauges and telemetry: It is adapted to low RPM because of the weight hooked up to the shaft
- Torquemeter: Expensive and complicated to install
- Optical with striped tape: This technique requires a rigid mounting of the probes and an accurate fixing of a striped target as shown in the figure below.

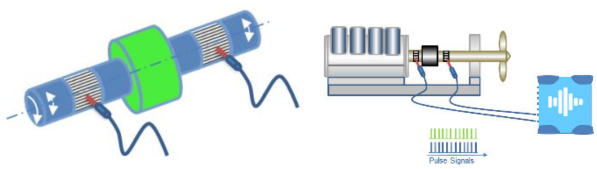


Optical sensor and encoding tape field installation

Based on that technique, with one sensor, one can deduce the angular velocity, the angle (after time integration) or the angular acceleration (after time derivation). If two sensors are used, the torque can be evaluated.



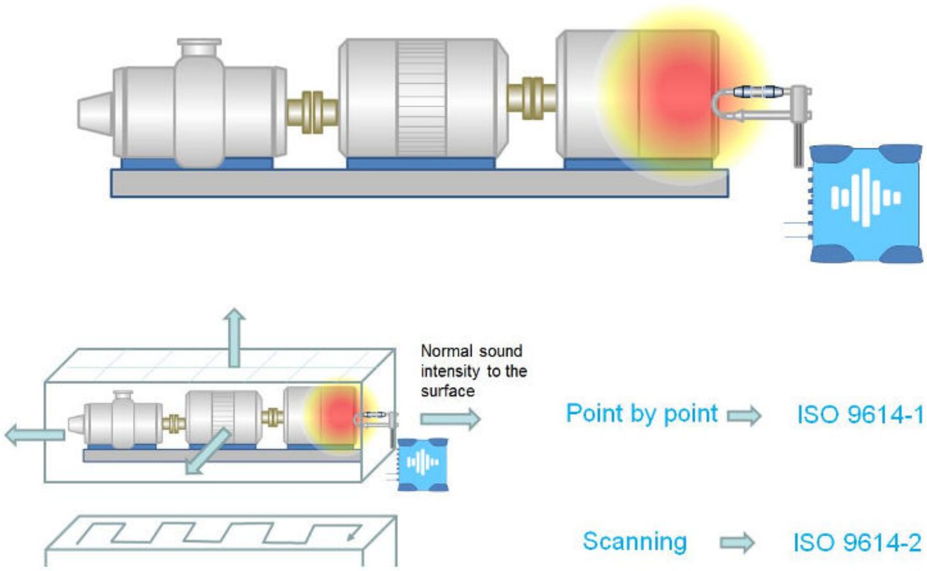
Single channel torsion with optical sensor



Optical sensor Dual Channel torque measurement

Noise source localization

An unexpected high noise level is often representative of a problem. It can also be a way to diagnose a problem on the machine. In that case, sound intensity can be a way to quantify the sound power emitted by the machine. And like thermography, it can also help locate the source of the problem.

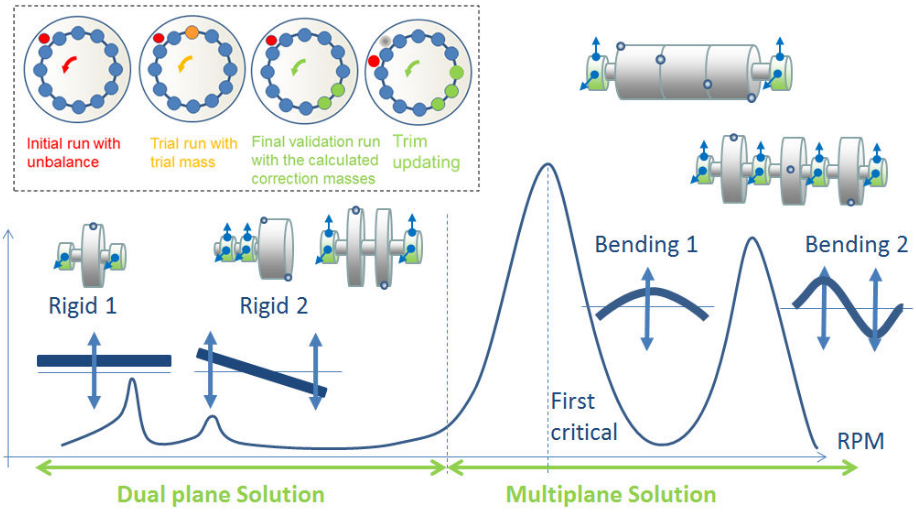


Sound power measurement based on sound intensity testing

Two techniques are used to calculate sound power based on a sound intensity measurement. The point by point technique (ISO 9614-1) takes more time but it allows to draw a sound map of the sound emission and so to unable the user to localize noise sources. The scanning technique requires the user just to scan the measurement surfaces with the probe in order to get one sound power evaluation per faces.

Single, Dual & Multiplane balancing

The balancing technique to be used has to be selected depending on the operation speed expected. If the operating speed is above its first critical, a multiplane balancing will be required.



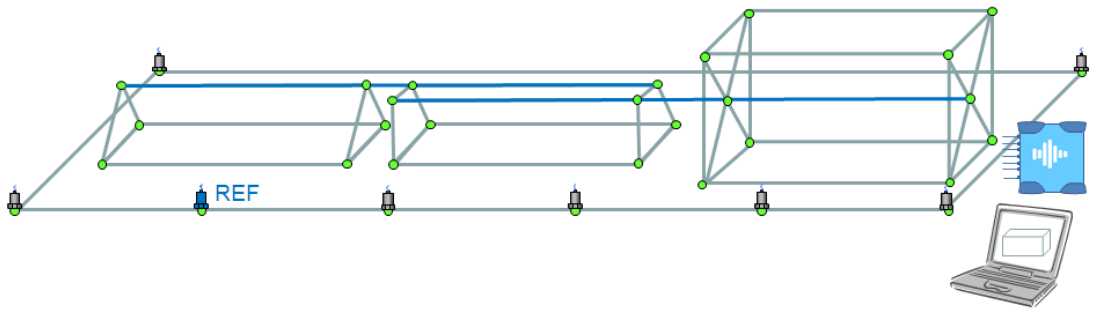
Balancing techniques applicable in the field or in the workshop

Operating Deflection Shapes (ODS)

Measuring vibrations with accelerometers or proximity probes at different points along the structure let the vibration analyst visualize the deformation of the structures:

- Foundation and skid
- Frame & Shaft
- Bearing housing
- End winding

One of the investigated positions should be used as a reference.



Measuring ODS on a turbine generator machine train

About Us

35-years in business, OROS' designs and manufacturing have been renowned for providing the best in noise and vibration analyzers as well as in specific application solutions.

Our Philosophy

Reliability and efficiency are our ambition everyday. We know you require the same for your measurement instruments: comprehensive solutions providing performance and assurance, designed to fit the challenges of your demanding world.

Our Emphasis

Continuously paying attention to your needs, OROS collaborates with a network of proven scientific affiliates to offer the latest of the technology, always based on innovation.

Worldwide Presence

OROS products are marketed in more than 35 countries, through our authorized network of representatives, offices and accredited maintenance centers.