Turbomachinery vibration analysis

OROS Webinar

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Application Engineer, OROS
Nicolas Denisot is an Application Engineer at OROS since April 2011. He is involved in after-sales actions to support a wide OROS customer base on-site, training them and helping them interpret measurement results. In pre-sales, Nicolas has a talent for understanding a prospect’s need, their testing environment and helps providing the right solution. This in a variety of fields, including turbomachinery trouble shooting, balancing and modal analysis.
Questions & Answers

⇒ Please write your questions in the Q&A area

⇒ We will take time to answer at the end of this webinar

Nick Hoffman

Joined OROS Americas in May 2020. Responsible for supporting US users and sales team. Recent graduate, worked NVH support from 2015 and consultation from 2017.
Webinar Recorded!

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Industrial Sectors
- Automotive
- Aerospace
- Energy and Process
- Marine
- Precision Machining and Process

Product Life Cycle
- R&D
- Acceptance
- Diagnostics

Applications
- Noise
- Rotating
- NVH
- Structural Dynamics
- Quality Process and Control
OROS – Noise and Vibration Testing and Analysis Solutions

Full Software suite
- Comprehensive
- Application oriented
  - Rotating
  - Structural Dynamics
- Data Acquisition and Signal Processing
- Acoustics

Services
- Customer Support
- Consulting & Coaching
- Customization & Integration

State-of-the-art Instruments
- From 2 to 32 channels
- Distributed up to 1000+
- DataCare®
- Flexible
- Made for any testing environment

Turbomachinery vibration analysis
* Contents

> Environment and instrumentation
> Turbomachinery diagnostic basic tools
> Focus on key features: full spectrum, sub harmonic level and run-out compensation
> Diagnostic with ORBIGate: case study
> Other techniques: ODS, balancing, torsion
Environment and instrumentation: Machine trains

Combined Cycle Trains

- Gas Turbine
- Generator
- Steam Turbine
- Hot Gas
- Steam

Turbomachinery vibration analysis
Environment and instrumentation: multi-physics transducers

- Tachometer / Keyphasor
  - Output > 10 V peak
  - OROS Analyzer: 40 V peak
Environment and instrumentation : multi-physics transducers

> Accelerometer IEPE (low temp.)
  OROS Analyzer : IEPE supply

> Velocimeter
Environment and instrumentation: multi-physics transducers

> Thermocouple

OROS Analyzer: XPOD conditioner

> PLC Process channel (Power...)

Turbomachinery vibration analysis
Acquisition from the control room

- OROS portable instrument connected to the buffered outputs
- Online monitoring
- OROS Analyzer: real-time analysis
Overview of basics tools

- Basic notions
- Overall levels
- Bode plot
- Waterfall
- Orbits analysis
Machines & Bearings

Rolling Element

Bearing Type

Sleeve

Typical Characteristics

• Stiff Bearings
• High Transmissibility
• Low Damping

Typical Machines

• Small Pumps and Fans
• Small Gas Turbines
• Cooling Tower Fans
• Most General Purpose Machinery

Special Considerations

• Large Gas Turbines
• Gear Boxes, Large Fans
• Boiler Feed Pumps

Casing or Bearing Cap Motion
(Accelerometers, Velocity Transducers, Twin Sensors)

Shaft Relative Motion
Eddy Probe Systems

• High Case; Rotor Weight Ratio
• Low Transmissibility
• Medium To High Damping

• Barrel Compressors
• Steam Turbines
• Large Motors
Absolute / Relative Vibrations

- Accelerometers or Velocity Sensor
- Absolute / Relative Vibrations
- Shaft/Casing
- Roller Bearing: Shaft & Casing vibrate « together »
- Journal Bearings: Shaft & Casing can vibrate independently
- Absolute Casing Vibrations
- Shaft/Casing Relative Vibrations
Overall vibration standard

> ISO 10816 Mechanical vibration — Evaluation of machine vibration by measurements on non-rotating parts

> ISO 7919 Mechanical vibration — Evaluation of machine vibration by measurements on rotating shafts
Overall vibration standard

> ISO 7919: overall trend for [10 Hz – 1000 Hz] versus speed
Fluid film bearings
RunUP: Shaft Center Line Position
AC \rightarrow Rotor vibrations

Orbit =

VIBRATIONS around the Shaft Centerline position during one rotation

Bearing Center

Shaft Average Position

Dynamic position (Orbit)
Vibrations

RPM

SHAFT VIBRATIONS → ORBIT
Orbit Shapes

The elliptical ORBIT

Response to an unbalance (1X) for an anisotropic bearing
Orbit Shapes

Unbalance

Unbalance + low natural freq

Whip orbit: Oil instability

Unbalance + Misalignement

Strong 1X + 2X close to resonance

2x on one probe: Misalignement
Critical speed & Bode plot

- Critical speeds are linked to bending rotor modes, when excited by imbalance (1X response)

  
<table>
<thead>
<tr>
<th>Mode number</th>
<th>Mode shape</th>
<th>Natural frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Bending</td>
<td><img src="image" alt="First Bending Mode Shape" /></td>
<td>51 Hz (3,079 rpm)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>52 Hz (3,129 rpm)</td>
</tr>
</tbody>
</table>

- Bode plot: 1X response magnitude & phase
Critical speed & waterfall

1X Bode plot

Critical speed

Eigen bending mode
Focus on key features

> Sub-harmonic level

> Full spectrum

> Run out compensation
Instabilities : High SUB1X

Excessive SUB 1X: Fluid Induced Instability

Stage 1: Oil Whirl appears

Stage 2: Oil Whirl becomes Oil Whip and locks to the first bending mode frequency of the rotor

Solution to that issue is to modify fluid circulation: bearing geometry, bearing gap, etc…

ORBIT PERIODICITY WRAPS AFTER SEVERAL ROTATIONS

SUB1X increase dramatically

Order Components below 1X increase greatly

1X

2X
Fluid film bearings

TILT PAD BEARING
Instabilities: High SUB1X

- Speed [RPM]
- Oil Whip
  - constant frequency
  - 1X
- Oil Whirl
  - constant order
- SUB 1X-0X-1X

Graph showing:
- Instabilities
- Oil Whip
- Frequency [Hz]
- Displacement [μm]
- Graph data points at [2X, 3X]
Sub-harmonic level

Sub-harmonic level: exclusive OROS feature
Key feature

> Full spectrum
Precession Direction: FORWARD
Precession Direction: REVERSE
Reverse Orbits

REVERSE ORBITS appear during SPLIT RESONANCES: Resonance in the Y direction appear after the one in the X direction.
full spectrum vs half spectrum?

> What is the correlation of it with half spectrum and/or with filtered orbits?
> What can it do for me?

> The full spectrum plot allows us to determine whether the rotor orbit are forward or backward
> The full spectrum is unaffected by probe orientation or probe rotation, as is the orbit
How is the full spectrum generated?

- **Raw orbit**
- **1X-filtered orbit**
How is the full spectrum generated?

1X orbit

Full spectrum positive and negative parts
Full spectrum: significant case

Circular orbit and forward $\Rightarrow$ no reverse component

Circular orbit and reverse $\Rightarrow$ no forward component
Full spectrum: significant case

Straight line orbit ➜ **forward** and **reverse** components amplitude are similar
## Trouble shooting with full spectrum

<table>
<thead>
<tr>
<th>Type of malfunction</th>
<th>Frequency component</th>
<th>Forward</th>
<th>Reverse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unidirectional radial load</td>
<td>1X</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>2X</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Rotor crack</td>
<td>1X</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>2X</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Full annular rub</td>
<td>1X</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Natural freq of the rotor-seal system</td>
<td>Low</td>
<td></td>
<td>High</td>
</tr>
<tr>
<td>Fluid-induced whirl</td>
<td>0.3-0.6 X</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Fluid-induced whip</td>
<td>Rotor natural freq</td>
<td>High</td>
<td>High</td>
</tr>
</tbody>
</table>
Runout Compensation

COMPENSATION PROCESS:
1. Evaluation at SLOW ROLL (often at the end of the ShutDown session)
2. Correction during the test
Overall Trend with and w/o correction
Runout Compensation

1X Polar diagram

VECTOR TRANSLATION
Live diagnostic with ORBIGate…
Typical Faults on Machine Trains

**ROTATING FAULTS**

- UNBALANCE (HIGH 1X)
- ROTOR BOW
- MISALIGNMENT (HIGH 2X)
- RUB
- FLUID-INDUCED INSTABILITY (HIGH SUB1X)

**STRUCTURAL FAULTS**

- ROTOR / STRUCTURE COUPLING
- MACHINE / FOUNDATION COUPLING
- GENERATOR STATOR END WINDING TESTS
Operational deflection shapes
MultiPlane Balancing

Turbomachinery vibration analysis
Torsional analysis

Figure 3: Pictures showing zebra tapes of sensor #2 located at the coupling between the steam turbine and the generator.

Figure 4: OROS analyzer, using over-sampled channels.

Torsional vibration resonance
Synchronous component due to the spacing error

Table 1: Comparison of natural torsional frequency between model and measurement.
Questions & Answers
Upcoming Webinars

> August – FFT Basics
> September – OR10 Introduction
> October – NVGate V12 Tips and Tricks

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