APPLICATION NOTE

Dynamic measurement on a bladed turbine disk

Mode shapes identification, *with Denek Kubin, R&D, SKODA Power.*

Introduction

SKODA Power, as an important supplier of **power generation technology**, needs to evaluate the vibration modes on their steam turbines. They propose here a procedure to obtain results using both simulation and experiment.
The Objectives of the application are to determine, with experimental tests and simulation results, the mode **shapes of the blades**, and to find a procedure to determine the correct mode shapes on a **rotating disk** with a family of axial, tangential and torsional excitations.

This application note will describe the hardware installation, the different measurements and the analysis made to obtain the wished results.

OR36 System

- Made for the field
- Rugged
- Rough
- Reliable
- Portable
- Comprehensive FFT plug-in: Triggers, weighted windows, cross functions
- Accurate: +-0.02 dB/ +-0.02°

OROS MODAL 2 software

Modern and user-friendly software with specific modules:

- Geometry building
- Operating Deflection Shape in time and frequency domain
- Modal Indicator functions
- MIMO identifications methods for EMA & OMA
- Modal Validation tools (MAC)

ŠKODA POWER

Skoda Power is part of Doosan Power Systems, a leading provider of: clean, efficient, flexible and integrated power solutions, using the latest technologies and best-in-class engineering expertise. From boilers and turbines to turnkey power-plant projects including nuclear and renewable power plants.

Doosan Power Systems unites the long heritage of excellence in turbo-generators from Skoda Power with boiler and air pollution control expertise from Doosan Babcock and Doosan Lentjes.

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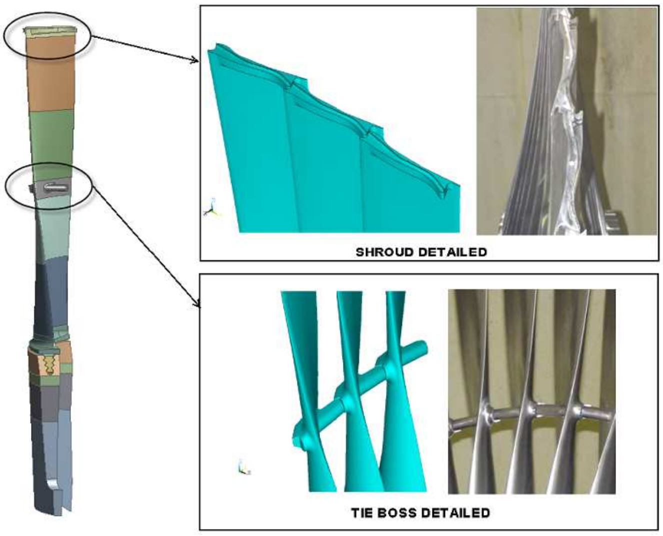
Skoda Power at work

Modal analysis on a blade

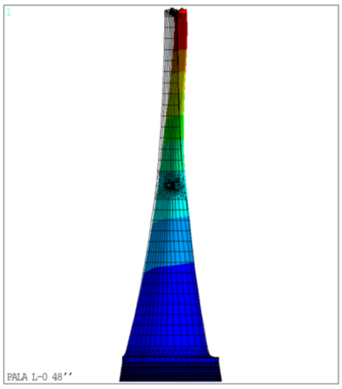
The length of the blades is 1220mm and there are two circle contacts (tie boss and shroud).



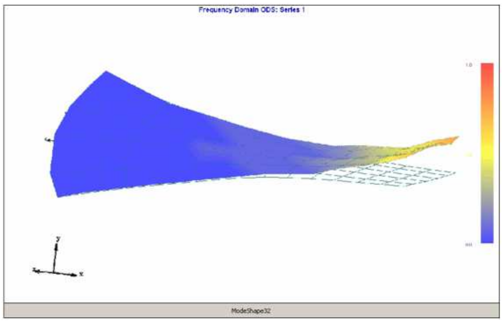
blades design

In the experimental approach, an OROS analyzer with OROS Modal 2 is used to acquire and analyze data from roving hammer test.

A good correspondence is found between numerical and experimental results.



Simulated mode shape from Ansys



Experimental mode shape from OROS Modal 2

Identification of vibrations modes on a continually shrouded bladed disk

Equipment:

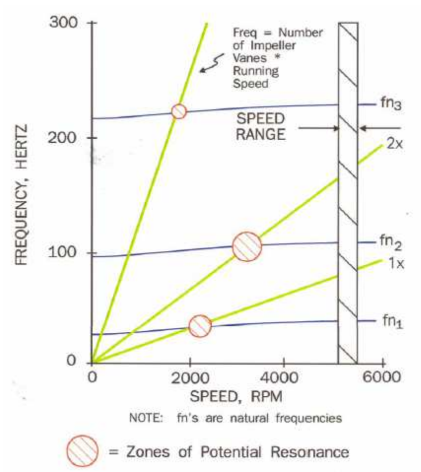
17 channels are activated on the OROS Analyzer. 14 strain gauges, 1 thermocouple, 1 magnet excitation frequency and a tachometer for the rotational speed are connected to the inputs. A slip ring and a ¼ bridge power amplifier are also used. Dynamic and static excitations are realized thanks to a magnet and respectively alternating and direct current.

Strain gauges on a blade

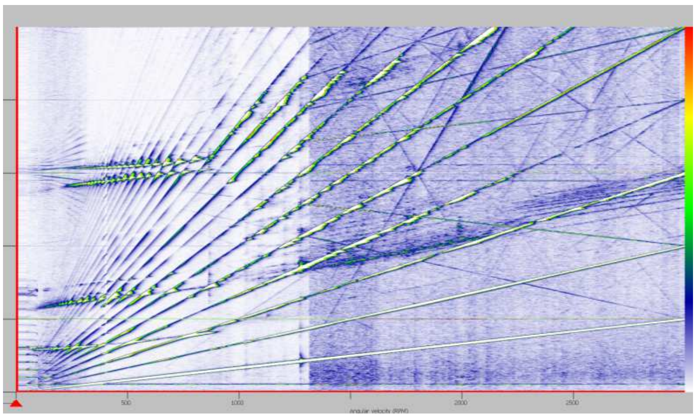
Test configuration with OR36

First step: Campbell diagram

The Campbell diagram shows all natural frequencies and resonances.



Theoritical Campbell diagram



Experimental Campbell diagram

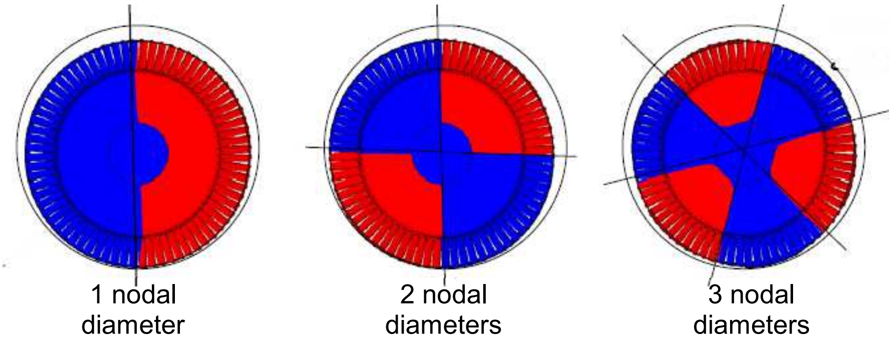
Practically, this type of diagram is not very usable for several reasons:

- There is only information from DC excitation (corresponding to direct RPM excitation) so not all frequency lines are included.
- There is a large amount of data containing a significant portion of noise.
- The interpretation of this diagram is difficult (close frequency lines).

This unique diagram is not acceptable for a good analysis, other tools are required.

Second step: Excitation and Interference diagram

An interference diagram shows the Campbell information and also where excitation forces intersect with nodal diameters.



Examples of nodal diameters

Using a fixed excitation magnet with an excitation frequency f_{EXIT} and resonance frequency f_{REZ}, a relationship exists for a given nodal diameter and backwards traveling wave:

$$f_{EXIT} = f_{REZ} + ND * f_{ROT}$$

Where:

- f_{ROT} = the rotational frequency of the disk
- ND = the number of nodal diameters

Considering one rotational speed for simplicity (i.e. 50 Hz) and using the relationship above, the diagram can be transformed into a diagram showing relationships between excitation and resonance frequencies. The red squares mark the areas of possible resonances. Excitation frequency is set by the harmonic function generator, power amplifier and magnet, measured by analyzer (measurement coil of the magnet).

Magnetic excitation

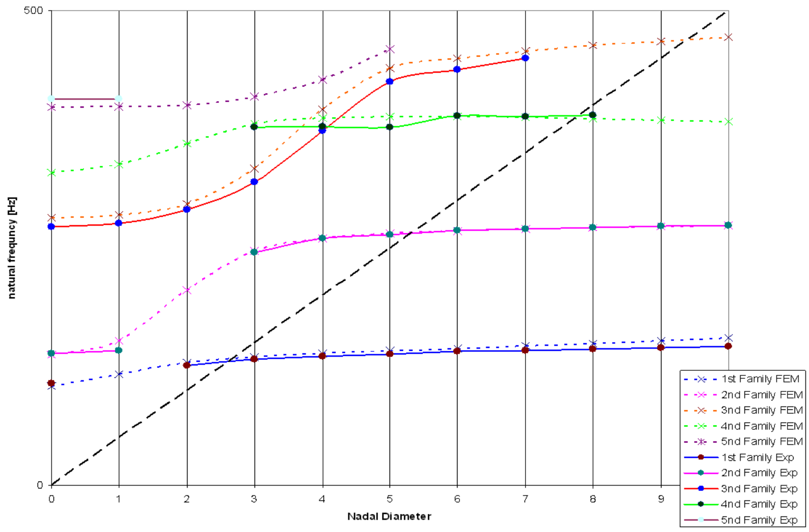
This evaluation is made with AC excitation.

Background noise elimination:

With this method we can see a noise displacement phenomenon. There are several methods to eliminate it:

- Statistical approach
- Kalman filtering
- Advanced method to find peaks.

A comparison between FEM and experimental results can be made:

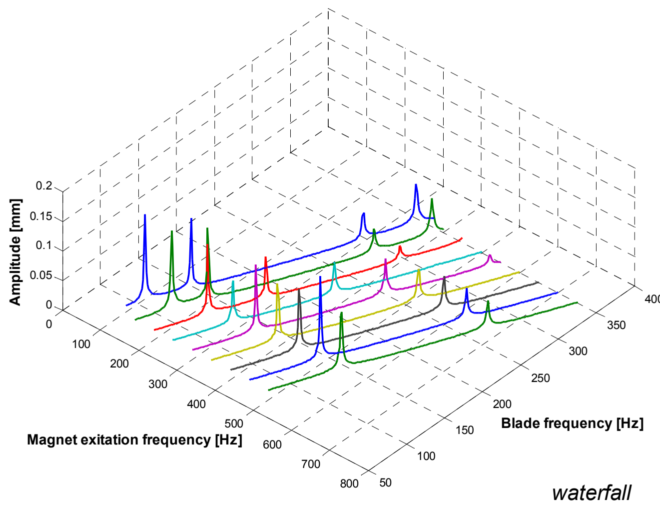


Interference diagram FEM-EXPERIMENTAL

Third step: The measurement results post processing

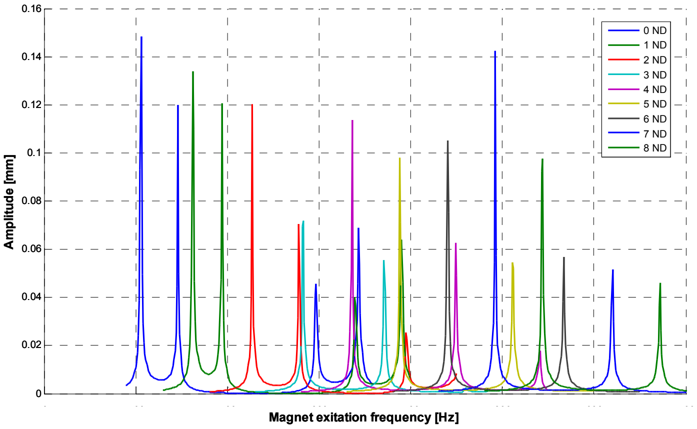
To get better view on the blade vibration during measurement, FEM forced response analysis is performed with the material damping 0,5%. Force excitation is harmonic with amplitude 100N applied at a tip location as in the Campbell stand. An in-house program for harmonic response analysis is utilized with mass and stiffness matrixes obtained from ANSYS.

For a fixed rotational speed (i.e. 50 Hz, 3000 rpm), a waterfall chart similar to the one below is measured. Instead of points corresponding to respective nodal diameters of each family, a series of emerging and vanishing peaks is observed. Typically, a requirement of the ± 5% distance between each vibration mode family peak and the resonant frequency is imposed. Visual check suggests whether this requirement is satisfied. The "forbidden bands" in the magnet excitation frequency are 100, 200, 300, etc. Hz ±5%.



waterfall

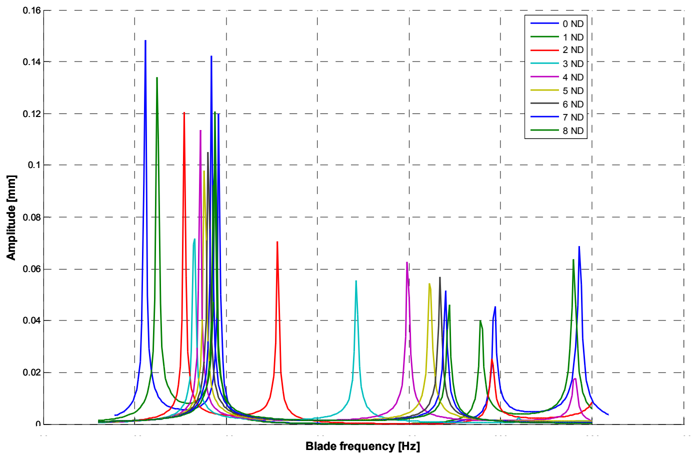
Figure below presents amplitude-frequency relationship. Similar ones should be obtained from the actual measurement as the function of the excitation frequency.



Amplitude-Magnet excitation frequency relationship

For most magnet excitation frequencies the response corresponding to specific eigen-frequencies (and ND) appears to be well separated in the range 100-250 Hz. For frequencies in the range 250-450 Hz the resonance peaks may overlap, so FFT needs to be used to separate corresponding Eigen-frequencies of the blades.

Each peak corresponding to diameter is identified directly from the data measured (sweep through the magnet excitation frequency with rpm fixed) or by tuning up the excitation frequency and looking for the maximum of the corresponding peak in the FFT.



Forced response analysis with blade resonance frequency on the X-axis.

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Forth step: Crosschecks

Following crosschecks should confirm that the estimated ND numbers and shapes are correct.

- Look at all 11 strain gages in (identical) positions and check identical frequencies in FFT for each strain gauge.
- Check the phase shifts at each strain gage location (time synchronized signal).

$$train\_gauge\_angle\_shift * ND = measured\_phase\_shift$$

$$strain\_gauge\_angle\_shift = \frac{strain\_gauge\_blade\_number}{total\_number\_blades\_in\_disc}$$

Gage - blade Nr.	Angle shift [deg]	Phase shift for corresponding ND*
1	0	0
8	38,2	ND*38,2
14	70,9	ND*70,9
21	109,1	ND*109,1
27	141,8	ND*141,8
34	180,0	ND*180
40	212,7	ND*212,7
47	250,9	ND*250,9
53	283,6	ND*283,6
60	321,8	ND*321,8

*for range 360 deg

Cross check table for estimated ND from the resonance measured and excitation frequency

Conclusion

Thanks to the complete integration between the analyzer and OROS Modal 2, the OROS solution is a perfect tool to evaluate the vibration modes on the steam turbines. For this application, the link with simulation software is a real advantage of the OROS solution to obtain suitable results.

Reference:

1. Misek, T., Kubin, Z., Duchek, K., 2009, “Static and Dynamic Analysis of 48" Steel Last Stage Blade for Steam Turbine“, in the Proceedings of the ASME Turboexpo: Power for Land Sea and Air, Orlando, USA.

OROS, Leadership through Innovation

About Us
Now approaching 30-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
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