Impact of Rotordynamics on Blade Vibrations – Guidelines and Practices

Abstract:

In all cases of new developments for steam and gas turbines, a rotordynamic assessment is required during the product development process. Usually, the complete shaft line has to be considered in such investigations, particularly the different rotors (gas and/or steam turbines and the generator), the bearings, the couplings and other important components influencing the rotordynamic behavior.

The numerical investigations are subdivided into the lateral and the torsional rotordynamics. They include for both cases the determination of the natural frequencies and the corresponding mode shapes. In addition, the forced vibrations have to be considered, mainly the unbalance response for the lateral vibrations and in case of the torsional vibrations a response due to harmonic air gap torques within the generator and the vibrations following an electrical fault (short circuit and faulty synchronization).

Besides the components as described before the blades of the turbine and the compressor influence the rotordynamic behavior as well. If the blade dynamics does not interfere
strongly to the rotordynamics frequency range, it is sufficient when the masses and the moments of inertia are added to inertia parts of the rotor. However, if the dynamic interaction between the blades and the corresponding rotor cannot be neglected, the blades have to be included in the rotordynamic assessment of both the lateral and the torsional vibrations.

This lecture will describe, how this interaction has to be considered, which blade stages should be considered, how the blades have to be modeled and attached to the rotor. The frequency dependence of the blade natural frequencies has also to be taken into consideration.

Examples will be presented and the effect of the Blade-Rotor-Interaction will be demonstrated and discussed in detail.

**Name:** Igor Tsypkaykine  
**Company:** Alstom Power, Switzerland

**Title:** Full Rotortrain Modelling Approach for Assessment of Dynamic Stresses on Rotor and Blades due to Torsional Disturbances

**Abstract:**
Torsional rotor vibrations with low frequency (e.g. 100 Hz for 50Hz standard generator) can be excited during normal operation by oscillating torques at the generator. For short turbine and compressor blades with high eigenfrequencies the excitation doesn't produce critical dynamic stress and can be neglected. But for long and flexible blades of last turbine and first compressor stages for large gas turbine engines the “blades-rotor” coupled system could come into resonance with the torsional excitation. Full rotor train model with flexible blades is required in order to accurately predict eigenfrequency and dynamic stress in the blades. Direct modeling approach is proposed which includes 3D FE blade models coupled with rotor/generator FE model. 1D, 2D or 3D FE mesh can be used for rotor model. Comparison of predicted and measured frequency is presented.
Name: Alexis Berranger
Company: Toulouse University & Turbomeca, France

Title:
Response Surface Based Multi Criteria Optimization of Turbine Wheels Fir-Tree Attachments.

Abstract:
Designing turbine wheels fir-tree attachments implies to satisfy numerous criteria. It involves three-dimensional finite elements analysis taking into account plasticity and time dependent behavior. These numerical analysis are time consuming and very expensive. Consequently, they cannot be directly used to optimize strength and robustness.

To work around this difficulty, we use mathematical response surfaces. They are built with a few calls to the finite elements model. With the great advantage of their short response time, response surfaces allow deploying optimization algorithms. The best geometries regarding performance and geometry mismatch robustness can then be obtained.

An example of mixed continuous-discrete variables optimization will illustrate our presentation.

Name: Jan Hlous
Company: Skoda Power, Czech Republic

Title:
Effects of Shrouded Blade Rings Assembly Procedure on Blade Coupling Conditions

Abstract:
As modern blade designs are breaking historical technical barriers to blade loading levels, adding extra damping is needed to improve blade resistance against excitation. For this purpose various ways of blade coupling are used. Performing FEM analyses is required to study the influence of manufacturing tolerances and assembly procedure. Within this presentation results of numerical simulations of bladed disk assembly procedures are discussed regarding blade-to-blade and blade-to-disk contact conditions and consequent
stress distribution. Experimental measurements were performed to verify the credibility of computational analyses.

**Name:** Simone Bistolfi  
**Company:** Franco Tosi Meccanica, Italy  
**Title:** Natural Frequencies of Shrouded Blade Rows: Sensitivity to the Shroud Contact Conditions

**Abstract:**
From non-linear dynamic behavior of a couple of shrouded blades in contact different linear “equivalent” models of the contact have been derived. Cyclic symmetry has been applied and the natural frequencies of the complete blade row have been calculated. The spreading of natural frequencies as function of nodal diameter numbers and of the used contact model (bonded in real contact area, no separation, with springs and dampers, with “contact pads”) is shown. Experimental results will help to select the “best” model.

**Name:** Giacomo Mondellini  
**Company:** Franco Tosi Meccanica, Italy  
**Title:** Dynamic Tests of Shrouded Blade Rows: Test Rig Design, Simulation Results and First Test Results

**Abstract:**
The design of a test rig for measuring the dynamic behaviour of a shrouded blade row sector with different contact pressures is described. Excitation with different engine orders is considered. Tests are numerically simulated by means of nonlinear calculations. Impulse test results on a bladed row of a stationary LP rotor are also shown and compared to calculated results.
Name: Malte Krack
Company: Leibniz Universität Hannover & SIEMENS, Germany

Title: Direct Parametric Analysis of the Forced Response of Bladed Disks with Friction Interfaces Using Analytical Contact Models

Abstract:
Optimization of the forced vibration behavior of tuned bladed disks subject to dry friction damping is a computationally expensive endeavor. In this presentation, resonance response levels and frequencies are computed directly as a function of the design variable such as the normal preload in the contact interfaces. The equation of motion is solved by means of the multi-harmonic balance method. Two analytical models with and without contact stiffnesses for the dry friction and unilateral normal contact are studied. Computational benefits in contrast to numerical contact models and the computation of the analytical gradients is pointed out.

Name: Hans R. Graf
Company: Sulzer Innotec, Switzerland

Title: Vibration Response of Coupled Blades with Detuning

Abstract:
Blades of disks and impellers are coupled with adjacent blades, resulting in groups of vibration modes and resonance frequencies. Blades are never perfectly identical, which may lead to dangerous vibration levels of individual blades.

By suitable intentional detuning of the blades it is possible to reduce the level of maximum vibration response, even with additional unknown random mistuning due to machining.
tolerances, fouling, or wear.

The effects of blade coupling, mistuning and intentional detuning are demonstrated using a very simple dynamic model. An algorithm for the optimization of detuning is introduced.

Name: Sebastian Tatzko
Company: Leibniz University Hannover, Germany
Title: Alternate Mistuning of Gas Turbine Blades Coupled by Underplatform Dampers

Abstract: Structural vibrations of turbine bladed disks lead to a reduced fatigue life of the components and thus to a reduced life of the entire system. A common way to reduce these vibrations is the well-known use of underplatform friction dampers between each two blades. Recent research concerning mistuning effects has also shown that there is a high level of sensitivity of the vibration amplitudes when the mechanical properties of two neighboring blades vary slightly. The consequence is in general much higher vibration amplitudes than predicted for the perfectly tuned system. A recently proposed intentional mistuning can make the system more robust against undesired effects, such as flutter. Furthermore, additional benefit with respect to friction damping may occur.

In this paper, an intentional alternate mistuning of a turbine blade is analyzed. Therefore, an existing simulation tool developed to analyze tuned bladed disks has been enhanced. Cyclic symmetry is used to reduce computational effort. One cyclic segment consists of two blades with different properties. Beside the blades also two different underplatform damper types can be considered in the calculation. Thus a damper mistuning with different damper shapes can also be analyzed. The mechanical modeling will be presented and explained. Simulation results show the effectiveness of different intentional blade/damper mistuning combinations.
**Name:** Zdenek Kubin  
**Company:** West Bohemia University & Skoda Power,  
Czech Republic

**Title:**
Determination of Natural Frequencies from Blade Tip-Timing Measurement Based on LMS Method

**Abstract:**
This work presents the use of LMS methodology to find blade natural frequencies in blade tip-timing (BTT) measurement with not equidistantly distributed sensors used for data acquisition. The Hilbert Huang Transform is used to perform the first frequency overview in narrow frequency band. The theoretically available frequency band is determined by the sampling depending on rotation. An aliasing effect causes mirroring of real natural frequencies into the mentioned narrow frequency band. After that, the major frequency peaks are identified and all their mirrors combinations in predefined frequency range are used to model the natural frequencies. Correct natural frequencies are estimated in terms of LMS method. Recursive LMS algorithm evaluates natural frequency amplitude and phase on each blade. Analysis of method preciseness is also described in this work. Finally, comparison of FEM computed blade frequencies with blade frequencies evaluated from operational signals concludes the paper.

**Name:** Harald Schoenenborn  
**Company:** Harald Schoenenborn, MTU Aero Engines GmbH, Germany

**Title:**
Aeroelasticity at Reversed Flow Conditions During Compressor Surge

**Abstract:**
The prediction of blade loads during surge is still a challenging task. In literature, the blade loading during surge is often referred to as “surge load”, which suggests that there is a single source of blade loading. In the presentation it is shown that the “surge load” in reality may consist of two physically different mechanisms: the pressure shock when the pressure
breaks down and aeroelastic excitation (flutter) during the blow-down phase in certain cases. This leads to a new understanding of blade loading during surge.

The front block of a multistage compressor is investigated. For some points of the backflow characteristic the quasi steady-state flow conditions are calculated using a RANS-solver. The flow enters at the last blade row, goes backwards through the compressor and leaves the compressor in front of the inlet guide vane. The results show a very complex flow field characterized by large recirculation regions on the suction sides of the airfoils and stagnation regions close to the trailing edges of the airfoils.

Based on these steady solutions unsteady calculations are performed with a linearized aeroelasticity code. It can be shown that some of the rotor stages are aerodynamically unstable in the first torsional mode. Thus, in addition to the pressure shock the blades may be excited by flutter during the surge blow-down phase. In spite of the short blow-down phase typical for aero-engine high pressure compressors, this may lead to very high blade stresses due to high aeroelastic excitation at these special flow conditions.

The analytical results compare very well with the observations during rig testing. The correct nodal diameter of the blade vibration is reproduced and the growth rate of the blade vibration is predicted quite well, as a comparison with tip-timing measurements shows. A new flutter region in the compressor map was detected experimentally and analytically.

Name: Josef Kellner
Company: Skoda Power, Czech Republic

Title: Determination of Crack Initiation on L-1 LP Steam Turbine Blades

Abstract: After ten years operation, one L-1 blade of steam turbine with large output power suddenly fell down. All 6 LP rotors (two machines) were checked and many cracks on L-1 blades were found. Due to economic reason, new blades were made with same geometry, but with better material in term of yield limit. Some L-1 stages were made from blades of original material, the rest was made from new material blades. Also the tip-timing measurement
was installed on two L-1 stages to monitor blades. The investigation of blade cracks reason started.

After one year of smooth operation there was an inspection. Surprisingly, the cracks were indicated again. The blades from new material had relatively more cracks than the original blades.

This presentation describes some computational analyses which were done. For example, the modal analysis and forced vibration of mistuned bladed disk and of whole rotor train with attached L-1 blades, CFX and CFD calculations were done.

The measurement of rotor torque, damping, Tip-Timing, experimental modal analysis of blades and rotor train and material test are also presented.

Application of both approaches (experimental and computational) rejected some hypotheses and revealed which hypotheses should be analyzed in a deeper way. The unstalled flutter has been identified as the most probable blade failures reason.