Blade Mechanics Seminar: Abstracts

ZHAW Zurich University of Applied Sciences
IMES Institute of Mechanical Systems in Winterthur, Switzerland

Wednesday, September 1, 2010
Lecture Hall, SM 01.01, Theaterstrasse 15c (Mäander), Winterthur

**Name:** Ronnie Bladh

**Company:** Siemens Industrial Turbomachinery AB,
Sweden

**Title key note presentation:**
The Aeromechanical Challenges in Industrial Turbomachines

**Abstract:**
High cycle fatigue continues to be a key challenge in the design of turbomachinery blading. The associated technical challenges facing the turbomachinery industry are to a large extent due to common development drivers for aero engines, mechanical drive, and power-generating units, such as aerodynamic efficiency, robustness and cost. Important distinctions are the constant chase for mass reduction in aero engines versus long-term integrity in harsh chemical environments for landbased engines. In both cases, however, modern blade design tends towards thinner, longer, and fewer highly loaded blades from the cheapest material possible, and it is left to lifing engineers to bring safely ashore the “sinking ships” that ambitious aerodynamicists and purchasers left behind.

In this talk, the principal sources of blade excitation are discussed: synchronous excitation from asymmetries and rotor-stator interaction, and non-synchronous phenomena such as rotating stall and flutter. Traditionally, resistance against these excitation mechanisms has been ensured through small incremental and thus conservative blade design upgrades in combination with an extensive experience base. Today, modern blade designs are breaking historical technical barriers, which render this traditional approach invalid. To overcome this challenge and to understand the physics of appearing blade vibratory behavior, modern numerical tools for
mistuned response and flutter predictions and tip-timing measurement technology have taken on an important role over time. Example applications of these emerging tools to industrial turbomachinery blades are provided. Particular attention is given to mistuning effects, whose understanding and accurate capture are pivotal for robust requirements on forced response margins and aeroelastic stability.

Name: María Mayorca
Company: Royal Institute of Technology, Sweden
Title: A Numerical Tool for the Prediction of Aeromechanical Phenomena in Gas Turbines
Abstract: The current work is concerned with the description and application of the numerical tool AROMA, which standardizes aeromechanical analyses for the prediction of HCF risk of turbomachinery components. The standardization permits performing parametric studies for determining the influence of accuracy or physical variations of key parameters on the final life prediction. Two study cases varying specific parameters are considered in this work: First, the variation of the blade count ratio and second, the number of master nodes in Reduced Order Modeling when considering mistuning. Simulations are performed in a transonic compressor and the final fatigue risk is assessed by making use of the aeromechanical tool. Finally, an overview of the possible physical and accuracy variations and their impact in the predictions is discussed.

Name: Florian Fruth
Company: Royal Institute of Technology, Sweden
Title: Influence of Blade Count Ratio on the Force Distribution and Blade Modal Properties
Abstract: The blade count ratio has been shown to have a significant influence on the blade forcing in previous 3D Navier-Stokes simulations on a transonic compressor. This presentation gives firstly further insight into the change in force distribution along the blade span and chord resulting from the different blade counts. Secondly, the changing mode shapes and frequencies are analyzed due to their influence on the final excitation. The impact of these varying unsteady forces and varying blade shapes is shown by means of the generalized force, giving indication of how the structural modes are excited by the fluid forces.
**Name:** Richard Setchfield  
**Company:** Rolls Royce plc, UK

**Title:** Predicting the Integrity and Life of HP Turbine Nozzle Guide Vanes

**Abstract:**
High Pressure Turbine Nozzle Guide Vanes (HPT NGVs) are complex components that are key to the efficient operation of the engine. Despite the absence of centrifugal or structural loads, the accurate prediction of HP NGV LCF service life in large civil aero engines remains a particular challenge for the Mechanical Design Engineer. This presentation illustrates an improved method for predicting the LCF life of these components. The method is an evolution of established rotor blade techniques allied with correlation factors to account for the differences in the mechanical environment and behaviour of the stator blade. The presentation highlights some of the challenges in obtaining both an accurate prediction of service life and a good quality correlation, and shows how these can be overcome.

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**Name:** Andreas Hartung  
**Company:** MTU Aero Engines, Germany

**Title:** Fast Resonance Passage Computation of Blades and Vanes

**Abstract:**
Standard aeromechanical analysis of blades and vanes vibrations includes frequency analysis, providing of a Campbell diagram and a forced response analysis with constant rotation speed and harmonic excitation. In the reality some resonance passages during a mission takes place. Calculation of a complete resonance passage from zero over the relevant rotation speed for a complete 3D Finite Element model leads to unacceptable computation time. In this presentation a method for fast resonance passage computation of 3D Finite Element blade and vane models is introduced and with some examples verified. Parameter studies and explanation of possible upgrading of the developed approach complement the presentation.
New Evaluation Procedure for Centrifugal Compressor Impeller Blade Vibration Measurements

Abstract:
For the examination of computationally determined natural frequencies and modes of centrifugal compressors, blade vibration measurements at standstill are performed. Natural frequencies and the associated number of knot diameters can be determined and be compared with computationally determined ones. Deviations from the design can be found reliably and - if necessary - suitable measures can be seized, for example impeller geometry corrections or restrictions of the operating speed range. With a new evaluation procedure, measuring data of the blade vibrations is evaluated quickly and without any user interference and the results are presented in a highly comprehensive manner.

Determination of Blade-Alone Frequencies of a Blisk for Mistuning Analysis Based on Optical Measurements

Abstract:
Meanwhile the importance of mistuning especially for blisks is well known. Most of the mistuning studies so far done are based on assumed statistical distributions of the eigenfrequencies. But it is important to know the real eigenfrequency distribution of the blades of blisks as they come out of the manufacturing process or after they are in service for some time and have experienced erosion, wear and FOD. Some of the current analytical procedures for mistuning calculations need the blade-alone frequencies, such as the reduced-order code Turbo-Reduce which is used in the subsequent analysis. One way to determine the eigenfrequency distribution is to ping-test every blade while damping all other blades. This procedure is very tedious and may take several days, depending on the number of blades.
In this paper a method for the determination of the eigenfrequency distribution based on optical measurements is described. Starting from the point-cloud a procedure to obtain a FEM-Model of all blades of a blisk is presented. As the whole procedure can be run as a batch-job, the time to determine the eigenfrequency distribution is drastically reduced compared to the experimental way.

The procedure is applied to a real blisk and the calculated eigenfrequencies are compared with the measured frequencies. Then mistuning calculations are performed based on this eigenfrequency distribution.

Name: Bernhard Klein
Company: ABB Turbo Systems, Switzerland

Title: Blade Crack Detection by Tip Timing Measurements During High Cycle Fatigue Tests

Abstract: Turbochargers with pressure ratios up to 5.8 are highly stressed engines. Due to the wide operation speed range the blade vibrations have to be below a certain level. Measurement of this level is part of ABB's development process. Also high cycle fatigue tests (HCF) are performed, which can be optimized using the non-contact blade vibration measurement technique (BSS). The presentation describes the current status of BSS and how BSS helps to detect cracks and reduce the throughput time for HCF tests.
**Name:** Ulrik Strehlau  
**Company:** BTU Cottbus, Germany

**Title:**  
Effects of Blade Mistuning on Frequency Veering Regions of Real HPC Blisks

**Abstract:**  
So-called frequency veering can occur in intersection zones of disk modes and blade modes, especially for blade integrated disks (blisks). MDOF or simplified FE-models are used to investigate the effect of blade mistuning on these regions. However, discussions in literature are still controversial.

Within this presentation a closer look at the appending mode shapes will be given in order to reveal the real behaviour, experimental as well as extensive numerical investigations based on a state-of-the-art HPC blisk, are used.

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**Name:** Tie Chen  
**Company:** ALSTOM, UK

**Title:**  
Comparison Between Two-Way and One-Way Coupling Tools

**Abstract:**  
To predict blade forced response, a commercial FE solver ABAQUS is linked with an in-house CFD solver TF3DVIB, in the time domain in both one-way and two-way couplings. In the two-way coupling, the structure equations are solved using Direct Integration, and the fluid equations are solved simultaneously using Shape Correction method. Both pressure and mesh displacement are exchanged at the fluid-structure interface at each time step. In the one-way coupling, the structure equations are first solved to extract the modal shape, and the fluid equations are solved separately to produce both aero forcing and aero damping. Then the structure equations are solved in Mode Based Dynamic Analysis to produce the blade forced response. Both methods are applied to analyse a freestanding turbine stage. At the blade structural resonant frequency, two-way coupling predicts only half of the peak response of the one-way coupling. Nonetheless, over a frequency range the peak response is very similar, but the peak response is shifted to lower natural frequency, due to the “added mass” effect of fluid-structure coupling. That means a speed / frequency sweep is necessary to search for the peak response in two-way coupling approach. However in one-way coupling, the
frequency shift can be derived from the vibration induced modal force, and only one calculation is needed to predict proper response over a range of frequency ratio. One calculation near resonant condition typically takes two-way coupling seven times more computing time than one-way coupling. The total computing time for two-way coupling to define the response characteristic is therefore much higher, considering that several calculations are needed to search for the peak. Thus the one-way coupling with frequency shift is practically the more suitable for blade forced-response prediction.

**Name:**  
Jürg Meier  
**Company:**  
Zurich University of Applied Sciences, Switzerland

**Title:**  
Use of Constrained Modes for Nonlinear Analysis of Shrouded Blade Rings

**Abstract:**  
In the nonlinear forced response analysis of systems with frictional contacts with the harmonic balance method (HBM), usually a modal description of the motion is used. These (linear) modes are calculated by omitting the contact connection. Subsequently, contact and friction are applied as forces to the system in the forced response analysis. With this procedure, the local stiffness in the vicinity of the contact (e.g. the shroud or snubber) is only very poorly represented in the analysis as it has an influence on very high modes only. In the lower modes, which are typically only used for the analysis, these elements behave like rigid bodies.

This drawback can be overcome by use of constrained modes: for the modal analysis, the contact is replaced by a linear spring element with a stiffness of similar order of magnitude as the contact. Therefore, the vicinity of the contact is deformed with similar stresses as in the nonlinear case, and the stiffness is represented well even in the low modes. Later on, the force of the spring is compensated in the forced response analysis, when the nonlinear contact and friction forces are added.

Potentials and limitations of the analysis with constrained modes will be presented on some typical examples.
**Title:**
A Direct Method for the Forced Response Calculation of Bladed Disks with Friction Interfaces and its Application to Blade Root Joints and Underplatform Dampers.

**Abstract:**
Realistic predictions of High Cycle Fatigue damage of turbine blades in service require reliable numerical tools to assess the vibration levels at resonance, taking into account the amount of damping at the friction interfaces.

A novel approach, based on the harmonic balance method, is presented for the forced response calculation of bladed disks with friction interfaces. It is based on the direct coupled solution of the static and of the dynamic balance of the system without any preliminary static analysis to compute the static contact loads acting at the contact interfaces.

The proposed method is applied to two common friction interfaces: blade root joints and underplatform dampers.