Global and Local Monitoring of System Dynamics and Grouted Joint Displacements at the Tripod Support Structure in *alpha ventus*

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   – Concept and Prototype
   – Recorded Data

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   – Fatigue estimation

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   – Modal Analysis
   – Condition Indicators
MONITORING OF GROUTED JOINT
Local monitoring at the Grouted Connection

• The **Stiffness behavior** of Grouted Connections is of high interest
• **Displacements between pile and sleeve** are needed to describe the stiffness behavior
• **No existing measuring system** is suitable for this field of application

➤ A new conception was created:
  – Sensor protection by an oil-filling
  – Flexible magnetically adaptable fixing structure
Manufacturing and Application

Installed measurement equipment:
• 4 Inductive displacement transducers (2 vertical, 2 horizontal)
• 2 dummy displacement transducers with constant measurement signals
• 1 temperature sensor
• 1 leakage measurement

Application offshore:
11\textsuperscript{th} August 2010

Start of data transmission:
2\textsuperscript{nd} November 2010
Measurement Data
5th February 2011
Wind: SW, 26 m/s

There is correlation between relative displacement signal and structural response as well as wave height.
LOCAL MONITORING
Measurement Data Assistant

• Goals:
  – Classify and categorize raw data from RAVE data archive
  – Provide a search function for certain load events
  – Provide a means to directly use measurement data in data analysis software without having to download them first

• Setup:
  – Server-based solution
  – Measurement data and search indexes are stored in efficient directory structure
  – Stateless Access via HTTP (searches are traceable)
  – Data is streamed to the client, no preparation of downloads necessary
  – All data are exchanged in structured plain text (CSV, JSON)
Fatigue approximation

• Fatigue depends on external parameters
  – External parameters depend on each other
  – Fatigue must be considered depending on combination of external parameters

• Goal: Approximation of fatigue for three cases
  1. Known parameters of time period in question
  2. Approximation for neighbouring turbine in same period
  3. Prognosis of the future

• Method: Fatigue approximation with a Monte Carlo approach
  – Determination of per-class distribution of fatigue (Rainflow, Palmgren-Miner)
  – Classification of parameters of base period and period in question
  – Approx. without strain measurements: Monte Carlo simulation of fatigue using computed distributions with classified parameters in question
  – For prognosis: distribution of parameter classes for base period and their sequence (Markov chain), simulation of possible future parameters using a Markov-chain-Monte-Carlo method
Fatigue approximation, results

Fatigue distribution for example class
- All external parameters have the same value

Approximation result for known parameters
- Dez.10 learned, Jan.11 approximated by external parameters and compared to measured strain (fatigue)
Approximation result for unknown parameters

- Fatigue prognose with MCMC simulation of external parameters
- Dez.10 learned, Jan.11 approximated without external parameters and compared to measured strain (fatigue)
Concept to analyze the huge data basis

Goals:

- Extraction of **modal parameters** for damage localization and quantification
- Extraction of **condition parameters** (damage existence)

Data pool from *alpha ventus*:

- Period: February 2010 – June 2011 / 17 Month
- Volume: **1000 GB** in binary .mat files
- **48,000 Datasets** of 10 min length each holding
  - 50Hz data of 44 Acceleration sensors and 4 Strain gauges
  - plus **Environmental and Operational Conditions** (EOCs)
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Concept:
Grouping all data sets by EOCs

- Here exemplarily EOCs: **Rotor speed** and **wind speed**
- **Occurrence** important for combining data sets to Groups

Rotor speed

Wind speed
Grouping all data sets by EOCs

- Here exemplarily EOCs: Rotor speed and wind speed
- Occurrence important for Selection of sets to Groups
- In the following slides: **One Group with 1596 sets**
Modal Analysis for selected data group
- 1596 sets

- Eigenfrequencies and mode shapes are important values for Damage detection and model validation
- In total: 20 Channels at five different levels were used
- Used Method: Data driven Stochastic Subspace Identification (SSI) for several model orders. Hence, more solutions than phys. modes; a distinction between mathematical and physical solution is needed
- 3d mode shapes can be calculated
  - Projection into nacelle KOS supports interpretation
Modal Analysis for single data set

1a
Frequency: 0.336Hz; Damping: 0.69%

1b
Frequency: 0.347Hz; Damping: 2.38%

2
Frequency: 2.458Hz; Damping: 8.52%

3
Frequency: 4.581Hz; Damping: 4.11%

4
Frequency: 8.481Hz; Damping: 1.75%
Condition Indicators give an idea about the structures state

- $\text{DI}_{\text{Null}}$: Indicator from Covariance driven SSI. A left Nulls pace is calculated for the covariance Block-Hankel-Matrix and compared between reference set and further sets.
Condition Indicators give an idea about the existence of damage

- **DI\(_{\text{Null}}\)**: Indicator from Covariance driven SSI. A left Nulls pace is calculated for the covariance Block-Hankel-Matrix and compared between reference set and further sets

- **DI\(_{\text{Prop}}\)**: Proportionality indicator for comparison of maximal strain level above Tripod and acceleration level below nacelle (both band-pass filtered for first bending mode)
Conclusions:

- Grouted Joint
  - Development of prototype measuring device for grouted joint displacements
  - Correlation between external loads (waves) and grout-displacements

- Local Monitoring
  - Data assistant for quick, local processing of measuring data
  - Calculation, approximation and forecast of fatigue

- Global Monitoring
  - Analysis of global system dynamics for model updating and later damage detection
  - Extraction of condition parameters to distinguish between healthy and unhealthy system states
Thank You for Your Attention!