Wind Energy
Vibration-based structural health monitoring
for tower and foundation of offshore wind turbines

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Vibrations experts

Vibrations
Structural dynamics
Acoustics

Engineering services
Systems
Software

90+ Employees
900+ projects / year

for SME and industrial customers
in Europe + internationally

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Projects / Systems – a selection: Foundation / Tower monitoring

- RWE Innogy – Nordsee Ost:
  - Measurement systems
  - Data analysis (online / offline) and decision making
  - Reports

- Iberdrola
  - Measurement systems
  - Data analysis (online / offline) and decision making
  - Reports

- WindMW
  - Data analysis

- EnBW
  - Measurement systems for Baltic 2
  - Data analysis for plant certification (Modal analysis: eigenfrequencies and modal damping)

- Nordex / Onshore:
  - Development of analysis software for calculation of tower bending moments and remaining lifetime by means of measured acceleration data
Purpose of the presentation

Preliminary results of the project UnderwaterINSPECT

- Test facilities: test hall and sand basin of TTH - Leibniz Universität Hannover (together with Fraunhofer IWES)
- Test rig: model of a plant with monopile foundation
- Sensors and hardware
- Purposes of the tests
- Preliminary results of data analysis
- Technical findings
- Further investigations
Experiments (test rig at TTH)

BD.10 shaker

2D-acceleration
2D-inclinometer
Strain gauges
Temperature
1D-acceleration

Level 9

Level 8

Level 7

Level 6

Level 5

Level 4

Level 3

Water

Sand

Scour

Level 2

Level 1

L = 6 m

l = 8 m

1.5 m

6.5 m

7.5 m

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Measurement of following structural states:

- References (no changes of the structure)
- Soil degradation
- Loosened screws at the flange
- Additional masses
- Scouring
- Inclined structure

Scopes:

- Learning of unchanged state
- Detection of soil degradation
- Detection of loosened screws
- Detection of fouling
- Detection of scouring
- Detection of inclination

Excitation: Stochastic loads (assumed as unknown) by means of BD.10 shaker

Data analysis tools (only preliminary data-driven algorithms):

- Operational Modal Analysis (OMA)
- Stochastic Subspace Fault Detection (SSFD)
- Time series models (ARMA family)
- Statistical properties of the data
- Pattern recognition algorithms
Soil degradation

- Change of the state indicator (here based only on the changes of 1st eigenfrequency)
- Probable cause of change: soil degradation
- Excitation: Random within frequency range of 2-50 Hz; RMS of excitation: 350 N
- Measurement time / data set: 10 min; sample rate: 500 Hz
Changes of 1st eigenfrequency during the measurements; RMS of excitation: 250 N

Damage, mass and scouring detection (1144 data sets)

Inclination detection (523 data sets)
Loosened screws and scouring: Indicators based on OMA

- 4 loosened screws
- 6 loosened screws
- 2 loosened screws
- scour -30 cm
- scour -60 cm
- scour -80 cm

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Loosened screws and scouring: Indicators based on SSFD

- 4 loosened screws
- 6 loosened screws
- 4 loosened screws
- 2 loosened screws

- +4 kg
- +20 kg
- +30 kg

- -30 cm
- -60 cm
- -80 cm

mass +4 kg
mass +20 kg
mass +30 kg

scour -30 cm
scour -60 cm
scour -80 cm

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Installation of hydraulic system → periodical eccentric loads

Mode participation: 1

Residual (°)

Measurement no.

Without sleeve

With sleeve

Inclination during loads from hydraulics

Remaining inclination

Inclination during loads from hydraulics

NS Level 4 at 2015.09.17

L1, L2, L3, L4

Remaining inclination

Z0094

RAVE 2015

PK, 2015/10/14, page 13

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Structure inclination after eccentric loading by hydraulics

Measurements during shaker excitation → OMA

Loads from hydraulics → inclination
Conclusion and further work

• Strong changes of the soil during the measurements
• Loosened screws can be well detected
• The effects of structure inclination are covered by the effects of soil changes
• The effect of the scouring on the dynamical properties is very strong → could cover effects caused by damage, etc. → additional sensors only for scouring monitoring?
• In the future the data from UnderwaterINSPECT will be analyzed by means of further mathematical data-driven and model-based approaches
• Measurements for the purposes of cut loads and remaining lifetime estimation will be used for the development of appropriate approaches
• Effects of grout damage will be examined during the QS-M Grout project
• Further environmental and operational effects on the plant dynamics observed in situ are considered in our monitoring algorithms
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Thank you for your attention!

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