Application of optical fibres for blade load measurement and condition monitoring

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What is an optical fibre?

FOS system

white light

Bragg sensors

Reflected light with wavelength equal to distances between “scratches”
What is an optical fibre?
Contents of presentation

• Introduction to ECN
• Introduction to condition monitoring
• Possibilities of optical fibres
• Test set-up
• Experience with optical fibres
• FOBM system layout
Introduction to ECN

Priority Areas
- Solar (PV)
- Wind Energy
- Biomass
- Clean Fossil (Fuel Cells)
- Policy Studies
- Energy Efficiency in the Industry
- Renewable Energy in the Build Environment
Introduction to ECN

Wind Energy

“With 45 employees the unit holds a strategic position between universities and industry covering all relevant wind energy disciplines; from trouble shooting to long term R&D, from training courses and design support to wind farm development and risk management.”

Four groups
• Wind Farm Development
• Wind Turbine Technology
• Wind Farm Operation
• Experiments
Introduction to ECN

Knowledge Centre WMC
(Wind turbine Materials and Constructions)

ECN Wind Turbine Test Farm Wieringermeer
Projects / Partners / Persons

DOWEC
*(Erik Korterink, Arno van der Werff)*
- NEG Micon Holland
- LM Glassfibre Holland
- Ballast Nedam
- Van Oord ACZ
- Delft University of Technology

FOBM
*(Luc Rademakers, Theo Verbruggen)*
- NEG Micon Holland
- FOS
- NGUp
- Baas R&D
Need for condition monitoring in wind energy

- Preventing damage and directly related costs
- Preventing revenue losses in case of damage, most significant for offshore wind energy
- Limiting the number of attendances (time to repair or inspection)
- Optimum planning using predicted remaining lifetime (seasons offshore)
Need for condition monitoring

33% + revenue losses

Retrofit & Overhaul 6%
Decommissioning 1%
Foundation 9%
Tower 9%
Wind turbine 24%
Electric Collection System 2%
Assembly, Transport and Installation 11%
Other 5%
Transmission System to Shore 6%
Yearly Operation & Maintenance 27%

Break-down of Generating Costs Offshore Wind Energy

Results from the DOWEC study
Condition monitoring is a proven method in other branches. The application in wind energy differs from the present application:

- Stochastic loading versus stationary operation
- Preventing damage versus enlarging preventive maintenance period
- Trade-off between higher investment and lower damage costs
Condition monitoring for wind turbines

Condition monitoring is applicable to many wind turbine components:

• **Blades**
• Drive train
• Main bearing
• Generator
• General behaviour (degradation of power curve)
• Other…
Possibilities for optical fibres

All possible failure modes of the blades have been investigated on possibilities for condition monitoring systems.

Some can be detected by a strain measurement; on basis of a changed strain distribution or a change in natural frequency or cumulative load spectrum.
Possibilities for optical fibres

Trailing edge transverse cracks (source Allianz)

Trailing edge transverse cracks (details, source Allianz)
Possibilities for optical fibres

Supposed of a measuring strains with an optical fibre versus classical copper strain gauges:

- Non-conductive, important for lightning
- More simple instrumentation
- More reliable in time

Advantages to be demonstrated in 2 year R&D project
Possibilities for optical fibres

Topics of research:

• Accuracy of measurement (zero drift, temperature influence)
• Reliability in time (opto-electronics, sensors)

Next to field tests, laboratory experiments are planned in the WMC
Test set-up

The DOWEC demonstrator / NM92 wind turbine at the ECN test site
Test set-up

108 m meteo mast
Distributed system:

- front-ends at different locations: sensor power supply and all signal conditioning, EMC proof
- glass fiber connections
- one central host pc: data collection and back-up, transfer to ECN database
Fibre Optic Blade Monitoring (FOBM) Applications for Wind Farm Operators

1. Converting raw data (strain) into meaningful parameters (loads, vibrations) for blade monitoring:
   - Assessment of loads (extreme loads, fatigue load spectra, consumption of lifetime)
   - Assessment of health and degradation
   - Design verification using design data

2. Informing operators about required O&M effort of blades
Example of time series
FOBM: Hardware

- Optical fibres in blades
- Data logger in hub
- PC for control and alarm
- Wind speed, Pitch angle, Power
- Strain, Loads, Spectra, ...etc.
FOBM: Network

Wind farm PC for data storage and trending

Alarms
FOBM: Remote Access

Wind farm 1 / Turbine 6

- Blade loads (fatigue)
- Blade loads (extreme)
- Strains (fatigue)
- Strains (extreme)
- Turbine loads
- Vibrations
- Design data and verification

No design data needed

Design data needed
FOBM: Remote Access

Wind farm 1 / Turbine 6 / Blade loads (fatigue)

- Flapwise bending moment
- Edgewise bending moment
FOBM: Remote Access

Wind farm 1 / Turbine 6 / Blade loads (fatigue) / Flapwise bending moment

- Time series
- Load spectrum (actual)
- Load spectrum (IEC class 1)
- Load spectrum (IEC class 2)
- Load spectrum (IEC class 3)
FOBM: Remote Access

Equivalent loads:
\[ N = CS^m \]

- Number of cycles
- \( C, m = \text{material properties} \)
- \( S = \text{equivalent load} \)

Wind farm 1 / Turbine 6 / Blade loads (fatigue) / Flapwise bending moment / Equivalent loads

- Turbine 6 (EIC class 2); \( S = 3.51 \text{ kNm} \)
- Turbine 6 (actual); \( S = 3.46 \text{ kNm} \)
- Turbine 2 (actual); \( S = 2.73 \text{ kNm} \)
FOBM: Remote Access

**Wind farm 1 / Turbine 6**

- Blade loads (fatigue)
- Blade loads (extreme)
- Strains (fatigue)
- Strains (extreme)
- Turbine loads
- Vibrations
- Design data and verification

N.B.: NO TEMPERATURE COM pensation
May 2003

FOSystem for reliable monitoring with no drift, after unloading strain is back to initial position

Tensile-Tensile test (0.04% - 0.18%) Back to no strain after 0, 255 000, 438 000 & 500 000 cycles

N.B.: NO TEMPERATURE COMPENSATION

-100
-80
-60
-40
-20
0
20
40
60
80
100

0 50 100 150 200 250

micron strain

Sensor #1
Sensor #2

START

After 255 000 cycles
After 438 000 cycles
After 500 000 cycles

255.000 cycles

500.000 cycles

Wind farm 1 / Turbine 6 / Vibrations

Frequency plots

Phase shift

FOBM: Remote Access

Wind farm 1 / Turbine 6 / Vibrations
FOBM: Remote Access

Wind farm 1 / Turbine 6 / Vibrations / Frequency plots blade 2

Select wind speed

- 4-8 m/s
- 8-12 m/s
- 12-16 m/s
- 16-20 m/s
- 20-24 m/s
- > 24 m/s
FOBM: Remote Access

Natural frequency of blade 2 at 14 m/s wind speed

Wind farm 1 / Turbine 6 / Vibrations / Frequency plots blade 2 / 12-16 m/s
FOBM: Remote Access

Wind farm 1 / Turbine 6 / Vibrations / Frequency plots blade 1 and 2 / 12-16 m/s

Natural frequency of blade 2 and blade 1 at 14 m/s wind speed

Blade 1  Blade 3
Any questions?