robust · reliable · fatigue-proof

STRAIN MEASUREMENT

for Wind Turbines
LEINE LINDE SYSTEMS GmbH
Hamburg

- Business Unit within HEIDENHAIN-Group of Companies
- Focussing on Wind & Renewable Energy
- Sales and Development of Products & Systems
**Robust & Reliable Strain Measurement at Wind Turbines**

**Strain measurement in wind turbines**

**Critical sections for strain sensors**

1. **Rotor blade**

   Rotor blades are the point of origin for generating the power and major system loads in a wind turbine. Special sensors in the rotor blades, particularly those located in the root position of each blade, are used to measure these individual loads. The data collected by these sensors can be used for additional condition monitoring, as validation between calculated and precise measurement data and for implementing new control concepts. For more efficiency and yield.

2. **Machine frame**

   The machine frame holds the main components (e.g., generator, gearbox) inside the wind turbine and serves as the link between rotor and tower. Wind turbine operation causes dynamic interactions among the individual components, which in turn subjects the machine frame to many complex loads. Sensor solutions used for this purpose are designed to measure the relative movement of the components in relation to each other as well as indicators for component wear and tear. The knowledge gained from these data enables adaptive WT control for load optimization. Costly downtimes can be reduced to a minimum.

3. **Tower and foundation**

   The trend toward larger rotor diameters and higher hub heights also cause an increase of the load on the tower and foundation of wind turbines. At the same time, these components are major cost factors and represent an ever-growing logistical challenge. A sensor-based, optimized WT control system can significantly reduce the loads in a wind turbine. This results in a noticeable reduction in component size and material cost.
Strain measurement in wind turbines

APPLICATIONS

<table>
<thead>
<tr>
<th>Calculation of Loads</th>
<th>Measurements of Turbine Dynamics</th>
<th>Turbine Control Integration</th>
</tr>
</thead>
</table>
| • Research & Development  
  • Validation & Certification | • Mode of operation  
  • Resonance  
  • Condition monitoring | • Extended monitoring  
  • New control strategies |

REQUIREMENTS

<table>
<thead>
<tr>
<th>Robust against</th>
<th>Reliability</th>
<th>Installation</th>
</tr>
</thead>
</table>
| • Temperature & Humidity  
  • Lightning strike  
  • Dirt | • Long lifetime  
  • Failure detection | • Easy installation  
  • Easy exchange  
  • Easy retrofit |
State of the strain sensor art

**Electrical sensor**

Strain gauge

**Optical sensor**

Fiber Bragg

Robust & Reliable Strain Measurement at Wind Turbines
ESR x25 Series
Main components

Stressless measurement of strain between two points
Passive compensation of temperature effects
ESR x25 Series
Measurement principle

25bit rotary encoder
Maximum sampling rate 100kHz
Temperature compensation by identical measuring arm material

Basic function:
Measuring the change in length between two points along the “length l”
The change in “length l” between two fixed points is transmitted to the measuring electronics via a measuring arm

Maximum deflection of +/- 5000 µε
Resolution of the strain sensor 0.025 µε

calculation of dynamic structural characteristics by scanning l
ESR x25 Series
Strain sensor with integrated electronics

**High precision**
- 25bit single turn encoder
- Resolution (Strain): 0.025 µε (200mm measuring length => 5nm)
- Measurement range: ± 5000 µε (200mm measuring length => 1mm)
- Temperature compensation by adapted measurement arm

**Reliability**
- Sensor based on proven encoder technology and high-volume production
- Protection Class IP64
- Lightning protection acc. IEC61400-24
- Stressless and fatigue-proof measurement

**Integrated diagnostics**
- Temperature check
- Sensor range reserve
- Plausibility checks
- Electronical name plate
- OEM memory area

Robust & Reliable Strain Measurement at Wind Turbines
ESR 125
Installation - adhesive version

Ready for use in 30-45min
(incl. preparation of test point, installation, hardening)
ESR 125
Recommended 2-component adhesive

<table>
<thead>
<tr>
<th>PLEXUS</th>
<th>MA 300</th>
<th>MA 310</th>
</tr>
</thead>
<tbody>
<tr>
<td>Working time (at 23°C)</td>
<td>3 to 6 minutes</td>
<td>15 to 18 minutes</td>
</tr>
<tr>
<td>Fixture time (at 23°C)</td>
<td>12 to 15 minutes</td>
<td>45 to 55 minutes</td>
</tr>
<tr>
<td>Recommended temperature during application</td>
<td>+18°C...+30°C</td>
<td>+18°C...+30°C</td>
</tr>
</tbody>
</table>

Temperatures below 65°F (18°C) or above 85°F (30°C) will slow down or increase cure rate.
ESR x25 Series

Sensor variants

- **ESR 125**
  - Adhesive installation
  - Material
    - GFRP
    - CFRP
    - Austenitic steel

- **ESR 225**
  - Adhesive adapter plate with threaded holes
  - Material
    - GFRP
    - CFRP
    - Austenitic steel

- **ESR 325**
  - Screw-on version
  - Material
    - GFRP
    - CFRP
    - Austenitic steel
### Application examples

Strain measurement on WTG-components during operation

<table>
<thead>
<tr>
<th>Rotor blade</th>
<th>Main frame</th>
<th>Tower</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Root section</td>
<td>• Generator support</td>
<td>• Top</td>
</tr>
<tr>
<td>• Middle section</td>
<td>• Torque arms</td>
<td>• Bottom</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
ESR x25 Series

Measurement reports and certificates

- Each ESR sensor is tested for proper functioning and measured for precision during manufacturing process.
- Based on article and serial number a quality inspection certificate is supplied with each sensor.
- Optional: On demand a DAkkS calibration according to DIN EN ISO/IEC 17025 can be performed.
EMS system tests

COMPARISON:
- Numerous comparative measurement to electrical strain gauges

ENVIRONMENTAL:
- Climatic chamber tests for evaluation of the sensor adhesive connection

ACCURACY:
- Several measurements to check sensor accuracy and repeatability

LIGHTNING:
- System immunity test due to lightning current according to IEC 61400-24

LAB TESTS
- Measurement during rotor blade fatigue tests (>50 m)

FIELD TESTS
- Various measurement campaigns on wind turbines in rotor blades and towers
Field test
Measurement in tower bottom of a turbine

Comparison to strain gauge signals

• Good match between strain gauge and ESR
• No offset-drift at high deformation levels
• Better signal-to-noise ratio through larger measuring distance
Field test
Measurement in blade root of a turbine

Comparison to strain gauge signals

- Good match between strain gauge and ESR
- Better signal-to-noise ratio through larger measuring distance
Field test

Rotor blade flapwise bending moments

Robust & Reliable Strain Measurement at Wind Turbines
Field test

Rotor blade edgewise bending moments

Robust & Reliable Strain Measurement at Wind Turbines
Field test

Rotor torque versus generator torque

![Graphs showing rotor torque versus generator torque for different measurements.](image-url)
Field test

<table>
<thead>
<tr>
<th>RESULTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Good match with strain gauge</td>
</tr>
<tr>
<td>• Higher reliability compared with strain gauges (several strain gauges failed during the test)</td>
</tr>
<tr>
<td>• No offset drift of the ESR</td>
</tr>
<tr>
<td>• Constant accuracy at high rotor speed (in comparison to the strain gauges)</td>
</tr>
</tbody>
</table>
EMS
Overview of available components and systems

- Strain sensor
- Fieldbus gateway
- Data processing unit

Robust & Reliable Strain Measurement at Wind Turbines
# Fieldbus-Gateways

## Variants

<table>
<thead>
<tr>
<th>Technical data</th>
<th>VRG 4:1</th>
<th>CRG 1:1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power supply</td>
<td>24 VDC</td>
<td>24 VDC</td>
</tr>
<tr>
<td>Current consumption (max.)</td>
<td>500 mA @ 24VDC</td>
<td>100 mA @ 24VDC</td>
</tr>
<tr>
<td>Protection class</td>
<td>IP 65</td>
<td>IP 65</td>
</tr>
<tr>
<td>Operating temperature</td>
<td>-25°C...+50°C</td>
<td>-40°C...+60°C</td>
</tr>
<tr>
<td>Sensor connection</td>
<td>8pM12</td>
<td>12pM23</td>
</tr>
<tr>
<td>Fieldbus connection</td>
<td>5pM12</td>
<td>5pM12</td>
</tr>
<tr>
<td>Electrical connection</td>
<td>Bis zu 4x EnDat 2.2</td>
<td>1x EnDat 2.2</td>
</tr>
<tr>
<td>Available fieldbusses</td>
<td>CANopen, POWERLINK</td>
<td>CANopen, PROFINET, PROFIBUS, Ethernet/IP</td>
</tr>
<tr>
<td>Accessible sensor information</td>
<td>Dehnung, Temperatur, Diagnose, Typenschild</td>
<td>Dehnung, Typenschild</td>
</tr>
</tbody>
</table>

Robust & Reliable Strain Measurement at Wind Turbines
# Data processing unit

## Variant

<table>
<thead>
<tr>
<th>Technical data</th>
<th>PDB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power supply</td>
<td>24 VDC</td>
</tr>
<tr>
<td>Current consumption (max.)</td>
<td>2000 mA @ 24VDC</td>
</tr>
<tr>
<td>Protection class</td>
<td>IP 65</td>
</tr>
<tr>
<td>Operating temperature</td>
<td>-25°C...+50°C</td>
</tr>
<tr>
<td>Gateway connection</td>
<td>3x M12, POWERLINK</td>
</tr>
<tr>
<td>Fieldbus connection</td>
<td>1x M12, CANopen</td>
</tr>
<tr>
<td>Ethernet connection</td>
<td>1x M12</td>
</tr>
<tr>
<td>Accessible information</td>
<td>Grafische Benutzeroberfläche mit Kalibrierung, Kurzzeit-Datenaufzeichnung, Benutzerrollen, Zustandsüberwachung, Diagnose</td>
</tr>
</tbody>
</table>
## User Cases

Software supported user cases

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Commissioning</th>
<th>Normal Operation</th>
<th>Maintenance</th>
<th>Monitoring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Configuration of hardware setup</td>
<td>Functional and fieldbus communication test</td>
<td>Continuous measurement of elongation</td>
<td>Staff training: only awareness, no special training needed</td>
<td>Condition monitoring</td>
</tr>
<tr>
<td>Configuration of WTG specific parameters</td>
<td>Semi-automated calibration sequence (depends on availability of SCADA signals)</td>
<td>Conversion to fieldbus data</td>
<td>Easy work with standard tool box</td>
<td>Structural health monitoring</td>
</tr>
<tr>
<td>Plausibility check on configuration settings</td>
<td></td>
<td>Comparison of limit values and actual values</td>
<td>Short delivery times for spare parts</td>
<td>Load monitoring (end limits)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>ESR electronic label for easy recognition of sensor parts</td>
<td>Recording of load spectrum</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mobile, battery driven diagnostic tools for the ESR</td>
<td>Ice detection</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>OEM memory space available (e.g. customer information)</td>
<td></td>
</tr>
</tbody>
</table>

Robust & Reliable Strain Measurement at Wind Turbines
Summary of benefits

EASY INSTALLTION
- Velcro fastening during installation
- Sensor installation up to 50% faster compared to conventional strain gauges
- Installation on different surfaces by 2K bonding
- Easy replacement with standard tools
- Sensors re-usable

INDUSTRIAL SCALE
- Robust and proven strain sensor technology
- Based on high-volume encoder technology
- Automated & scalable in-house production lines

RELIABILITY
- Redundant system designs allows further turbine operation and increased uptime
- 3-level plausibility checks secures safe operation within turbine design loads
- Subsequent electronics (computing) based on reliable standard PLC technology
- Algorithms based on standard C libraries

APPLICATIONS
- Short-term measurements
  - Highly accurate strain measurement
  - High sampling rate (e.g. turbine dynamics, resonances, noise)
  - Load measurement (IEC 61400-13, DIBT, FGW)
- Long-term measurements
  - Operation time extension (DNVGL-ST-0262)
  - Individual Pitch Control (IPC)
  - Turbine control optimization

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