

Fibre optic blade strain monitoring

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Operation and maintenance is a key cost in offshore wind turbine installations. Optical strain gauge technology can allow continuous and remote monitoring of blade condition, says **Luc Rademakers**

Fibre optic blade strain monitoring



Operation and maintenance (O&M) of offshore wind turbines is one of the main cost drivers for offshore wind energy, where site visits can be very expensive. At present, OPEX cost contributes approximately 25% to the Levelised Cost Of Energy (LCOE). Condition based maintenance presents an attractive means to control the O&M costs of wind turbines and – compared to corrective maintenance – can reduce downtime, minimise the consequences of damage, improve planning of activities, and enable better use of resources and equipment. The result is an overall reduction in cost.

A number of systems are already available to monitor the condition of wind turbine components. SCADA data, drive train monitoring, visual inspections and oil sampling are commonly used and have all proven their value. However, these techniques only start to provide useful information when the components are already exhibiting evidence of degradation or failure.

On the basis that degradation of a component is strongly related to the loads acting on it, the Energy Research Centre of the Netherlands (ECN) has been

developing a fibre optic system capable of accurately monitoring the mechanical loads in the rotor blades, where most of the loads are introduced. It has developed a low cost method that monitors blade root bending moments and processes the data in such a way that turbine operators can decide if and which maintenance action is required. This information can be used to prevent failures, to postpone or prioritise visits, or to decide on extension of the turbine life.

The specifications for the fibre optic load monitoring system are based on ECN's previous experience in measurement of wind turbine characteristics and its understanding of the shortcomings of electrical strain measurements. The procedures for data processing, analysis and reporting are in line with IEC standards for wind turbines.

The system consists of:

- A patented easy to install sensor assembly with fibre Bragg gratings, that requires no calibration, and provides reliable, accurate and reproducible strain data over a very long period (four assemblies per blade); ►

Right: Strain gauge mounted in its protective case.

Far right: Detailed view of one of the mounting studs.



- A commercially available interrogator to read out the data from the fibre optic sensors;
- A measurement computer that derives load data from strain data and combines the blade load data with turbine PLC data;
- Wireless-LAN to enable communication between the rotor and the turbine base;
- Software for data processing that filters and cleans up the time series, categorises the data per design load case, and provides key figures, statistics, and graphs to the operator for O&M optimisation;
- Additional software that combines measured blade root bending moments with SCADA data and also generates loads for other main components like drive train and tower top.

Schematic showing a typical optical strain monitoring system set-up

Sensor assembly

The sensor assembly is intended to be easy to install and replace by regular wind turbine maintenance

technicians with no special skills on fibre optics (plug-and-play). System installation in less than two days was the target. Key design considerations included the ability to accurately measure the average strain over a well-known distance to avoid the effects of non-homogeneities in the blade, elimination of on-site calibration, and the ability to provide the same working lifetime as the blade itself. The following technical specification was determined:

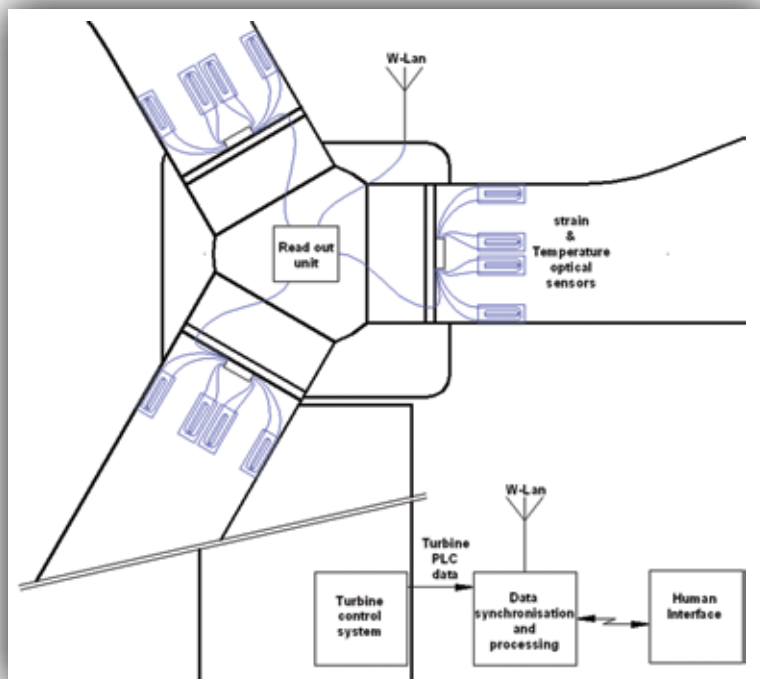
Strain resolution	: 1 $\mu\epsilon$
Strain accuracy / stability	: better than 5 $\mu\epsilon$
Maximum strain level	: -1000+1000 $\mu\epsilon$
Long term drift	: less than 5 $\mu\epsilon$ in one year
Temperature range	: -20...+40 °C
Long life time	: > 10 ⁷ cycles @ $\pm 1000 \mu\epsilon$

The resulting sensor consists of a fibre with a Bragg grating mounted between two studs via a carrier. The studs are mounted at a mutual distance of 100 mm to the inner side of the blade root. The carrier ensures that the fibre follows the displacements of the studs and with this approach the strain in the blade root is measured over a sufficient length to avoid local effects of the blade material.

The carrier protects the fibre from sharp bending and also accommodates a second Bragg grating for temperature compensation. Since each strain sensor is compensated by a local temperature sensor, the effects of temperature differences over the blade can be detected. The fibre is manufactured with draw tower grating technology from FBGS International and has proven to have a very high ultimate strain (up to 6%). The assembly can easily survive the life time of the turbine.

Installation Aspects

The sensor is suitable for applications in both existing turbines (retrofit) and new blades. Since all assemblies are calibrated after production under well-defined conditions, on-site calibration after repair is not necessary, which keeps downtime to a minimum.



Technicians are provided with a dedicated battery operated tool that allows quick mounting, accurate mutual positioning and glueing of the studs on the surface of the blade. Prior to bonding of the studs, the specific areas of the blade are ground. An adhesive with a short curing time (15 minutes at 20°C) and which can survive the dynamic loads is used to secure the studs. The complete mounting time takes just 20 minutes including curing time.

A dedicated sensor housing is also mounted during the curing of the stud connection. This includes a base plate and removable cover and enables simple installation, inspection, and replacement of the sensor.

Finally, the technicians mount the carriers on the studs, using only four bolts for rigid connection, and plug-in the patch cables into the two E2000 connectors. The protective covers are attached to the base plates to shield the sensors from moisture and impact. After the sensors are installed, the interrogator is mounted in the hub, the PC is installed elsewhere in the turbine, and all devices are connected with electrical cables and optical fibres.

The entire measurement system is designed to limit the amount of onsite work – most of the preparatory work can be done in the workshop – and first runs have shown that the tight installation schedule of less than two days can be met.

Read-out Unit (Interrogator)

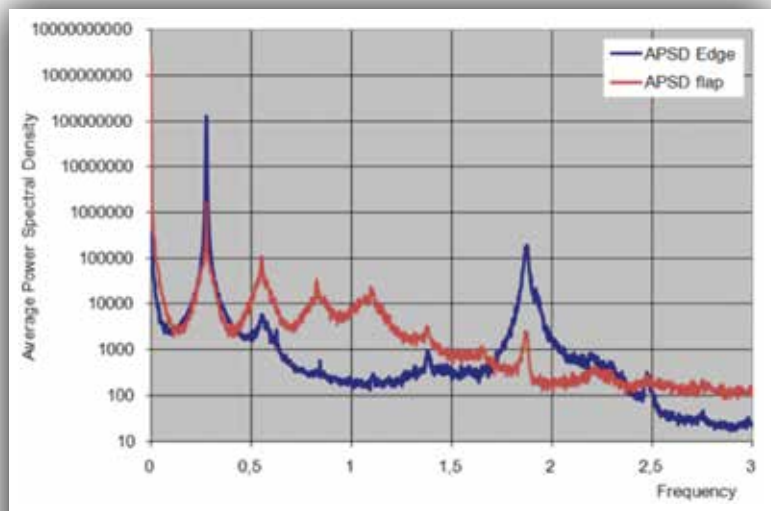
Specifications for the read-out unit for wind turbine applications are: a minimum wavelength range of 1520-1580 nm, strain resolution of 1 $\mu\epsilon$, strain accuracy/stability of better than 5 $\mu\epsilon$, sensor readout frequency of greater than 16 Hz, and ability to support eight Fibre Bragg Gratings per blade (four strain and four temperature).

Various suppliers provide interrogators that meet these general specifications. At present ECN uses the WindMeter from FibreSensing. This device is based on WDM technology for readout of the sensors and is especially designed for wind turbine applications. It has three channels, is available in a robust housing and has a minimal power consumption. The maximum frequency readout frequency for the sensors is 100 Hz.

Software for Data Analysis and Reporting

ECN's software automatically analyses the large amounts of raw data and provides information to operators about accumulated loads, extreme loads, dynamic behaviour and vulnerable spots. The software contains an algorithm that first cleans and filters the data and removes spikes.

The software detects the load cases (operational



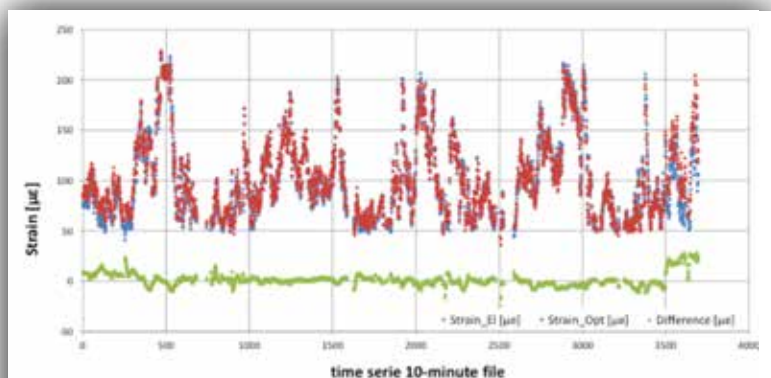
Frequency plots (av. power density). Example of APSD of edgewise and flapwise bending

modes) present in the time series, possibly splits the 10 minute time series into single mode files, and stores the data with statistics of the single mode files into the relevant database field.

The identification of the load cases is performed based on turbine PLC signals such as power, nacelle wind speed, rotational speed, etc. ECN has also developed software that reads out the database contents and generates reports, plots, and key figures that the operator can use to make sound decisions for operation and maintenance. The data processing software contains two main processes:

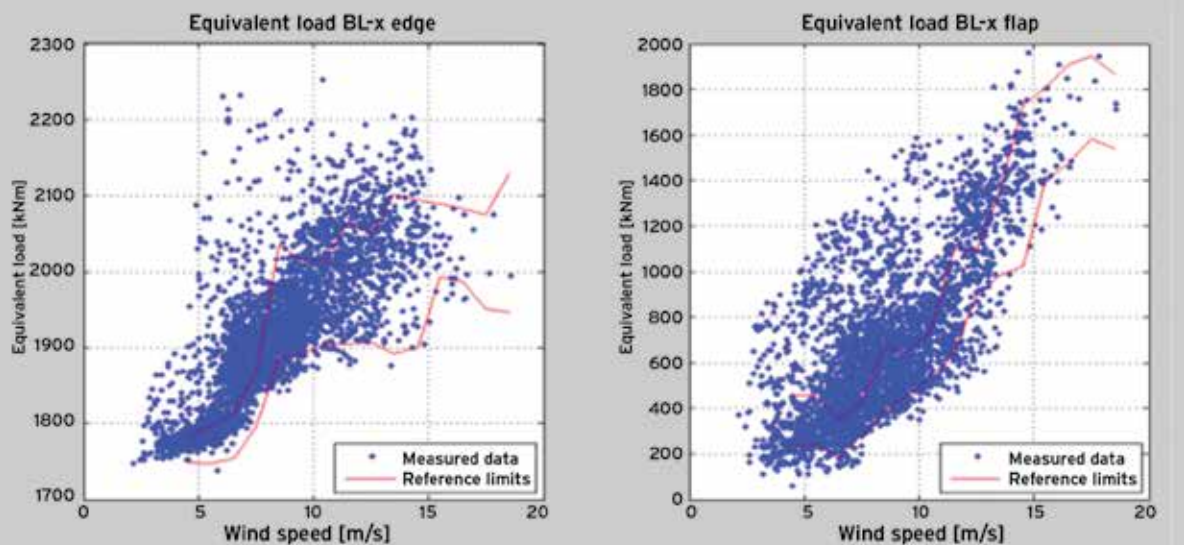
- An on-line module which continuously collects and processes the relevant data from the measurement system and subsequently stores the results in a database;
- A reporting module, which provides online access to the database and generates periodic reports.

Both processes function independently with a database as the interface between the two parts. Once the measurement campaign is running, the software



Comparison of 10 minute values for optical (red) and electrical (blue) strain measurement, with difference (green)

Equivalent loads:
Example of plots with the equivalent load as a function of wind speed (10 minute average) during normal operation



determines every 10 minutes which load cases have occurred (normal operation, start-up, shutdown, emergency shutdown, etc.) and filters out erroneous data. Then the software determines statistical data, updates the load spectra plots, and analyses the frequencies. Finally, the software is able to generate monthly reports which provide information about captured data, deviations with respect to the long term statistics, and comparison with finger print data.

User experience

The fibre optic load monitoring system has been developed as a device to measure blade root bending moments in operating wind turbines over a long period of time with high accuracy and long term stability. It has been operating for several years in one of ECN's test turbines and many field and laboratory tests have been carried out and comparisons have been made with strain gauge measurements.

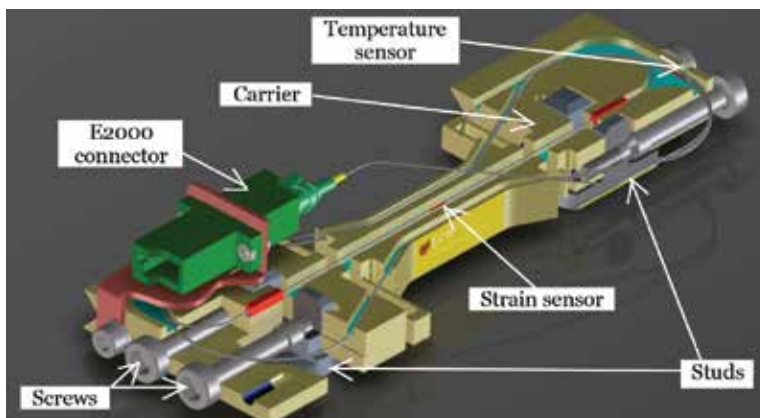
While the ECN system can be supplied as a complete solution, the component parts – including the software – can also be supplied for integration into an existing monitoring system.

The system has shown to be stable over a long period of time and operate within the required accuracies. Fatigue and ultimate tests have shown that the sensor system meets the design specifications. The software for data analysis has also proven to work well. ECN is about to install the first system in a commercially available turbine.

Compared to electrical strain gauges and patches with optical sensors that are glued directly onto the blade (or are integrated with the blade), the ECN sensor design has a number of benefits:

- Mounting the sensor assembly is on two studs positioned 10 cm apart means measured strains avoid the local influences of in-homogeneities, small gaps, and/or stress concentrations that can occur in reinforced plastics.
- Sensors installed during blade manufacturing can be removed during blade transport and installation to minimize the risk of damage.
- Installation of the sensors does not require any changes to the blade manufacturing process, allowing it to be offered as a simple option to clients.
- The optical-based solution is insensitive to EMC and can be used in flammable and explosive conditions.

Illustration showing the location of key components in ECN's test turbine



Click on the links for more information:

- www.ecn.nl
- www.fbgs.com
- www.fibersensing.com

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