TECHNOLOGY REPORT

Dynamics and Strength Testing

High dynamic loads have to be taken into consideration during the operation of wind turbines. It is therefore essential to perform static and dynamic strength tests and fatigue analysis on the rotor blades of wind turbines.

The issue of materials (composites) used and their strength is an ongoing issue due to the size of wind turbines, whose blades will soon exceed 100 m in length, with power generating capacities of up to 8 MW.

The Danish Test Center BLAEST in Aalborg specializes in the testing of wind turbine components. The BLAEST test center, co-owned by the leading wind technology institute Force Technology, the Technical University of Denmark (DTU – Risø) and Det Norske Veritas – German Lloyd (DNV-GL) operates several test stands for strength and fatigue testing of rotor blades.

The strength of each rotor-blade prototype has to be tested before approval and mass production. These tests are carried out in accordance with IEC 61400-23. BLAEST is certified for the complete test.

Multilevel test procedure

Up to 400 strain gauge measuring points are distributed along the blade. Controlled force loads are applied at 4 to 8 positions on the blade. Initially a static test is performed, in which the blade is subjected to 110% of the nominal worst-case load for approximately 10 seconds. In addition, temperature, humidity and deflection are measured at 5 to 20 positions by means of displacement sensors.

The measurement is performed with a sampling rate of 500 Hz, and a data file is generated every minute. If the blade breaks, the data rate makes possible to analyze the fracture sequence. If the test piece survives the test, the individual data files are assembled into a project file.

Fatigue testing is carried out after the static test has been completed. This simulates a typical lifespan of 20 years. The load is applied „flap-wise“ and „edge-wise“, i.e. in two directions. The blade is subjected to 1 to 5 million load cycles in each direction over a period of 1 to 5 months. This corresponds to about 2 load cycles per second. BLAEST can test blades with a length of up to 90 m.

Subsequently, an additional static test is performed, where the results indicate how well the rotor blade has withstood the fatigue test. The graph (Fig. 1) shows, for example, the strain at one position on the blade. The strain grows to about 5,200 micrometer/m; at this level of strain the material starts to tear. The strain abruptly changes to about 6,000 micrometer/m, and exhibits an asymptotic oscillation of approximately 1 Hz. Superimposed on this vibration is a further approximately 20 Hz of vibration, which subsides after about 3 to 5 periods of the basic oscillation. To be able to evaluate these tests it is essential to have accurate, synchronous data acquisition with a sufficiently high data sampling rate and a correspondingly large measurement range.

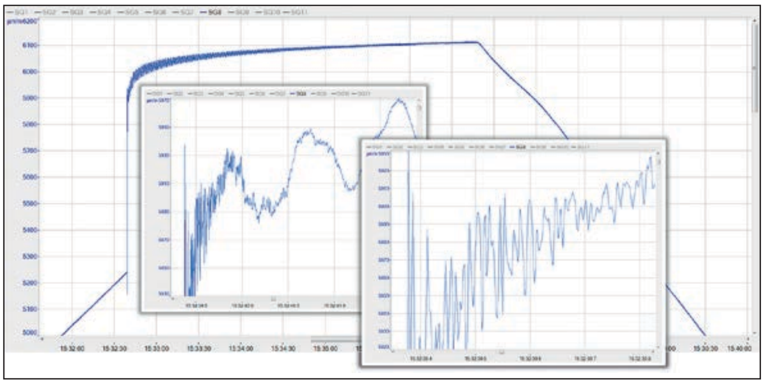

Fig. 1: Increase in load up to destruction of the blade

Fig. 2: The Q.bloxx A116 data acquisition module for strain-gauge measurement

During the modernization of their facilities, they decided to replace their existing data acquisition systems. When selecting the measurement system, which is primarily intended for detecting strain, BLAEST set the following priorities:

- Long distances between the measuring points and the measurement device
- High temperature stability

About the Author

Dipl.-Ing. Reinhard Kehrer is Managing Director and shareholder of Gantner Instruments Test & Measurement GmbH.

- Selectable measuring ranges for small strains up to fracture
- High synchronicity of the measuring points with each other
- Flexible configuration of 400 strain gauge positions.

After extensive tests, BLAEST chose Q.bloxx A116 data acquisition modules for strain-gauge measurement from Gantner Instruments.

Long distances between strain gauges and data acquisition module

Due to the size of the rotor blade, long cables are necessary between the individual strain gauges (quarter-bridge) and the data acquisition system. These can negatively influence the measurement in two ways:

A massive bridge asymmetry occurs due to the cable resistances, which is, however, compensated by the conventional, three-wire circuitry. This causes a cable resistance in series with the strain gauges and a cable resistance in series with the internal completion resistor.

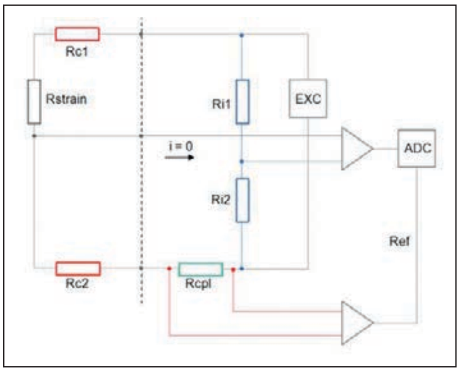

Fig. 3: Gantner Instrument's three-wire circuitry with compensation of cable influences

However, the usual three-wire circuitry is not able to compensate for the voltage drop of the supply voltage. This results in a faulty measurement due to the proportionately lower measurement signal. Attempts to compensate for these drops in voltage, based on an additional fourth wire, result in increased wiring complexity and necessitate more expensive measuring channels.

With the A116 data acquisition module, Gantner Instruments utilizes methods which compensate the influence of the classical three-wire circuit, even with very long cables. Measurements at BLAEST with cable lengths up to 120 m have shown that the cable effect is negligible.

The circuitry is based on the fact that the current flowing in the extremely high impedance input amplifier is zero. The supply current thus flows through the two cable resistors, the strain gauges and the supplementary resistor. By measuring the voltage across the precise completion resistor, the voltage drop can be determined via the cable resistors and compensated in the measuring module.

Calculation with assumed values:

Strain 500 micrometer/m

k factor 2

The resulting specific relative strain-gauge resistance change is 1 milliohm/ohm

The absolute change is 0.35 ohm, the strain-gauge resistance Rstrain at 500 micrometer/m is 350.35 ohm

Bridge supply is 4 VDC, internal half-bridge resistors 1,000 ohm

Cable resistance Rc is 10 ohm (cable length approx. 100 m)

Using this compensation method in the Q.bloxx A116 data acquisition module, accurate quarter-bridge strain-gauge measurements can be made without cable resistance having any effect.

Der Strom errechnet sich aus

$$I\,loop = \frac{Vexc}{Rstrain + Rc1 + Rcpl + Rc2}$$

$$I\,loop = \frac{4\,V}{350{,}35\,\Omega + 10\,\Omega + 350\,\Omega + 10\,\Omega} = 5{,}55286\,mA$$

Das Messsignal ohne Kompensation ist

$$Vsig = I\,loop * (Rcpl + Rc2) - \frac{Ri2}{Ri1 + Ri2} * Vexc$$

$$Vsig = 5{,}55286\,mA * (350\,\Omega + 10\,\Omega) - \frac{1000\,\Omega}{1000\,\Omega + 1000\,\Omega} * 4\,V = -0{,}97175\,mV$$

Dies ergibt rückgerechnet ein Dehnungssignal -485,875 µm/m und damit eine Abweichung von 14,125 µm/m, was 2,83 % entspricht.

Wird der Spannungsabfall über dem Ergänzungswiderstand gemessen und zur Korrektur verwendet, ergibt sich die Rechnung

$$Vref = I\,Loop * Rcpl$$

$$Vref = 5{,}55286\,mA * 350\,\Omega = 1{,}9435\,mV$$

Durch das Verhältnis V_{sig} zu V_{ref} wird der Kabeleinfluss eliminiert.

$$VADC = \frac{Vsig}{Vref}$$

$$VADC = \frac{0{,}97175\,mV}{1{,}9435\,mV} = 0{,}5000$$

Die Dehnung von 500 µm/m wird somit unabhängig vom Kabelwiderstand gemessen.

High temperature stability

High temperature sensitivity is ensured especially with quarter-bridge, strain-gauge measurement because the strain gauges experience a completely different temperature than the supplementary resistor in the measurement device. An extremely stable temperature of the supplementary resistor is therefore of utmost importance. A temperature-related resistance change of 0.1% would correspond to an elongation of 500 micrometer/m. Strain measurement thereby quickly becomes temperature measurement. In the Q.bloxx A116 data acquisition module each measurement channel utilizes 120 and 350 ohm completion resistors with a temperature stability of 0.05 ppm/K. Changes in temperature of 10K thus result in deviations of only 0.025%. Accordingly, the variations in resistance with poor temperature stability are higher:

5 ppm/K → 2.5 %
1 ppm/K → 0.5 %
0.5 ppm/K → 0.25 %
0.1 ppm/K → 0.05 %
0.05 ppm/K → 0.025 %

Every user should pay special attention to this because less stable resistors are often used for cost reasons.

Selectable measurement ranges for small strains up to fracture

Every measurement technician knows that the better the measuring range is adapted to the measurement signal, the better the results. This is particularly true for noise, drift and stability. Strain-gauge signals in voltage tests range from just a few microvolt/V up to 10 mV/V where materials are tested to their breaking limit. It is unrealistic to try to cover these signal dynamics with one range. Either the range is, as is often the case, around 2 mV/V (corresponding to a quarter-bridge 4,000 micrometer/m), which is used for small but not for larger strains, or the measuring range, for example, is 30 mV/V (60,000 micrometer/m), which is then completely unusable for small strains.

Example: A manufacturer gives a max. deviation of 0.05 % full-scale. In the area of 2 mV/V (4,000 micrometer/m) this is 2 micrometer/m. But if the specification refers to a range of 30 mV/V (60,000 micrometer/m), then a calculation error of 30 micrometer/m would occur. This would make the strain-gauge measurements carried out, for instance, by BLAEST, unusable.

The Q.bloxx A116 data acquisition module provides two selectable measuring ranges from 1 mV/V (2,000 micrometer/m) and 10 mV/V (20,000 micrometer/m). In addition, 2 bridge supply voltages are available. The higher voltage for a good signal-to-noise ratio, and the lower voltage for measurements with small strain gauges on plastics.

Beispiel:
Signalfrequenz 20 Hz
Periodendauer = 50 ms, entspricht 360°

$$Fehler = \sin \frac{360° * Jitter}{Periodendauer\ T}$$

Bei einem Jitter von 100 µs ist der Fehler bereits 1,25 %, bei 500 µs ist er schon über 6 %.

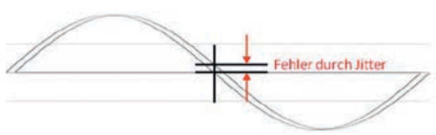

Fig. 4: Influence of non-exact synchronized measurement data: Jitter of only 1 microsecond in the Q.bloxx A116 strain-gauge module causes negligible influence of 0.0125%.

High synchronization of measuring points between themselves

For dynamic measurements, a measurement rate of up to 500 Hz was selected. This represents no challenge for a system with 400 channels. However, the jitter between the individual signals may be only a few microseconds. And, that is not always guaranteed. Often systems need to be synchronized by means of complicated software (FPGA), via inaccurate time server (SNTP) or via special synchronized lines which do not necessarily work over long distances.

The Q.series data acquisition system has a modular structure, in which all individual measurement modules can be connected to a Q.station controller. This ensures that all signals are synchronized with a maximum jitter of 1 microsecond. It is thereby possible to obtain correlated measurement values and evaluate them in relation to each other.

400 flexibly configurable strain gauges

The modular structure of the system permits a flexible arrangement of the measurement equipment to exactly fulfill the requirements of the application. Up to 500 measurement channels can be measured by one Q.station test controller; these are immediately synchronized to within 1 microsecond. The measurement system communicates with the parent host as one unit via a single interface and setup. All measured values are displayed in an image of the process and are transmitted as one set of data without any further configuration. It is also possible to combine any measurement channels in the controller for arithmetic or logic operations.

Fig. 5: Configuration of a measurement system with up to 500 channels based on Q.series instrumentation

This ensures that the system can be expanded to meet the changing needs of users without adaptation work. Simply connect up modules, download a new configuration and continue the measurement.

The persons responsible at BLAEST appreciate this simple configuration: „Our engineers and technicians need significantly less time to configure a test sequence. The simple, simultaneous and voltage failsafe taring of all 400 channels is excellent. In addition, thanks to the open interface we are able to include the configuration of the measurement system in our own test software. We are able to quickly and reliably adjust the 400 measuring channels with name of the measurement point, the k factor, the offset, the filter frequency, etc.“

Summary

In conclusion, Gantner Instruments would like to thank BLAEST and especially Mr. Søren Kjær Nielsen, who gave this assessment: „With the Gantner system we have better compensation of the cable influence and greater accuracy, which in turn allows us to provide our customers with higher quality test data. The extraordinary accuracy of our tests has been confirmed by our customers and certification bodies. Measured values correspond perfectly with calculated values. We use Gantner's test.viewer software, which is also preferred by our customers. Due to the higher sampling rates, we are also able to use this software to perform online FFT analysis. We can view things during the formation of cracks that were not previously aware of. We could also take advantage of the improved accuracy and higher sampling rate to optimize the controller function when exerting loads on the rotor blades. Both we and our customers are very satisfied."

KONTAKT

Gantner Instruments Test & Measurement GmbH
www.gantner-instruments.com