Whitepaper
Inspection Technologies for Wind Turbine Rotor Blades

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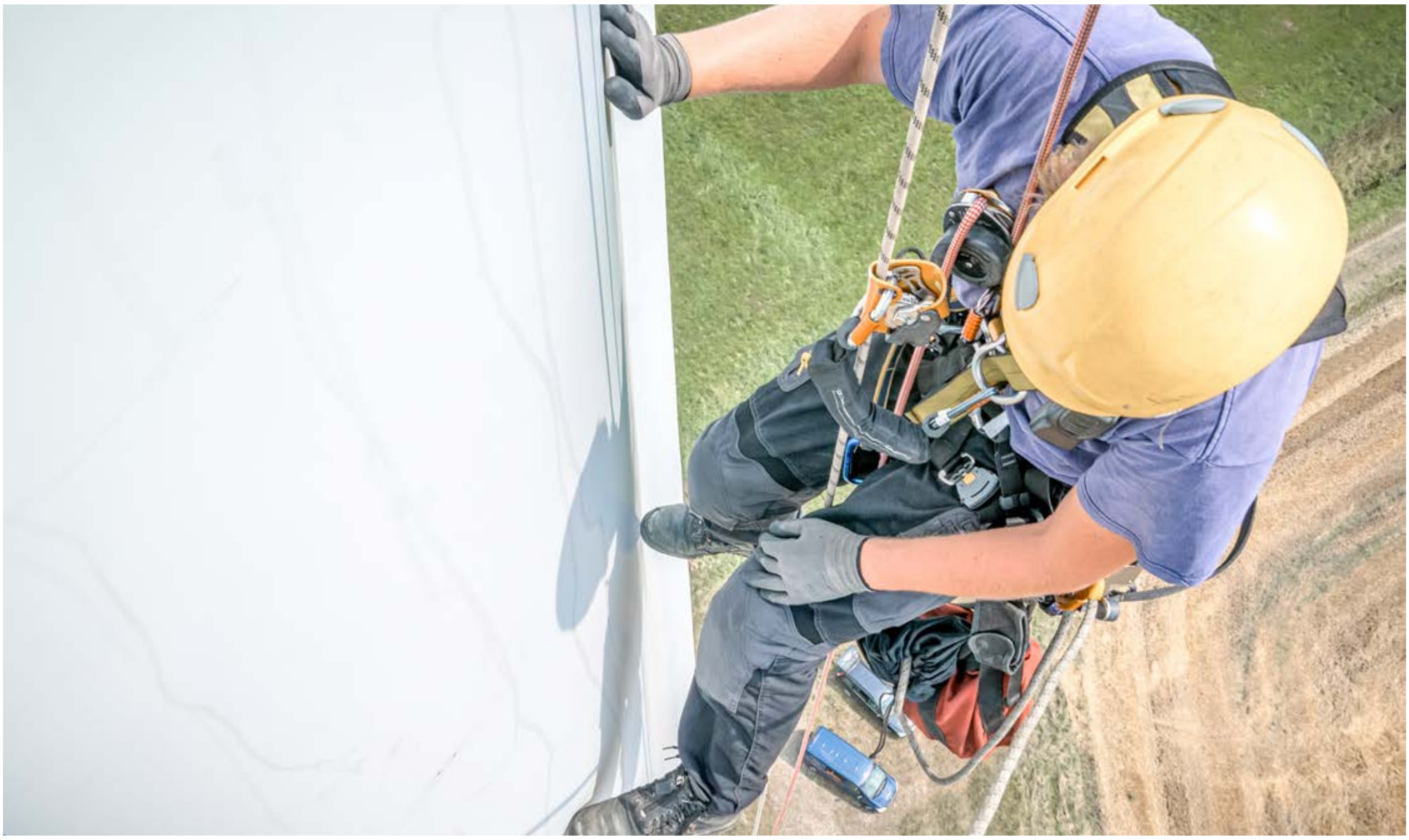
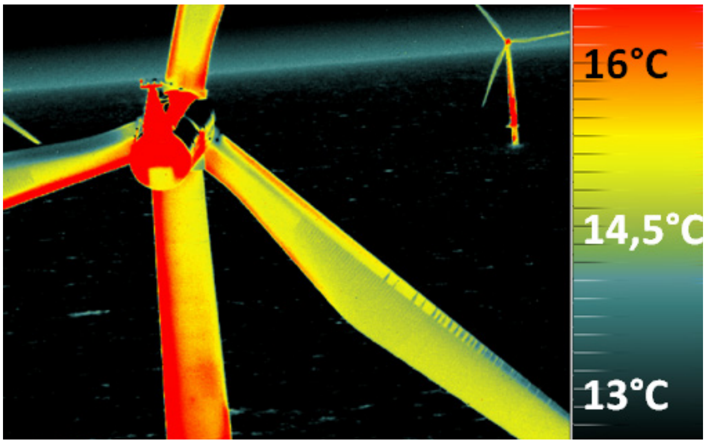


SURFACE INSPECTION TECHNOLOGIES IN WIND INDUSTRY

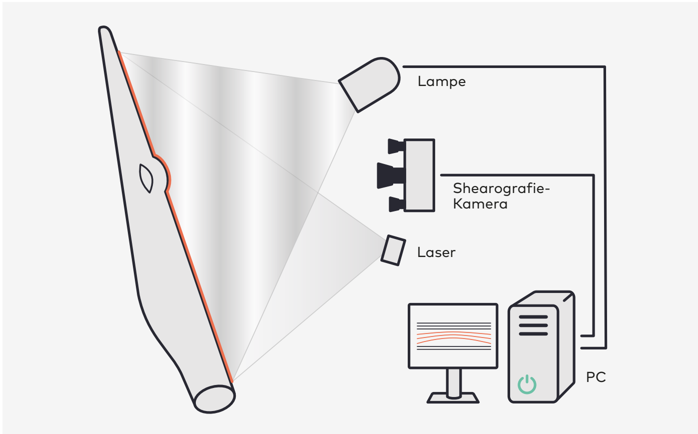
Quality control of wind turbine rotor blades is complex and requires consideration of various aspects. Different inspection technologies are available. However, not every inspection technology is equally suitable for all aspects of wind blade quality. Hence, selecting the appropriate inspection method is crucial for efficient and effective quality control. For this, knowledge of the capabilities and limitations of existing technologies is essential.

At the same time, conflicting goals, for example, regarding the use of resources, the required accuracy, and the sensitivity (probability that a specific, existing quality defect will be detected during inspection), must be considered. In short, a higher likeliness that the presence of a particular quality defect will cause catastrophic failure of the component and high consequential costs during its lifetime directly leads to a higher reasonable effort to detect the defect within the quality assurance process. In principle, quality defects can be categorized according to different characteristics. Examples include the type of defect (e.g., structural vs. cosmetic), the associated risk ("severity"), or the suitable inspection method for detection and evaluation.

This article outlines and explores the possibilities and limitations of different inspection methods. In addition to various imaging methods based on optical, thermal, and acoustic measuring principles, the article also considers "manual" inspection by an experienced expert using only simple, non-digital measuring equipment.



BUNDESANSTALT FÜR MATERIALFORSCHUNG UND -PRÜFUNG/ SCANDAT GMBH

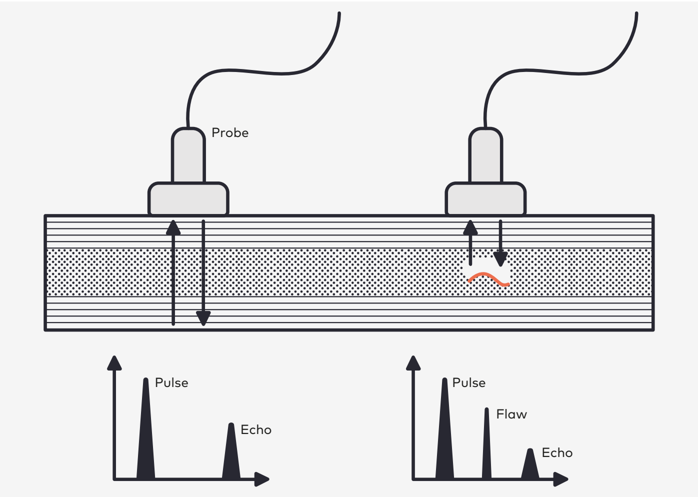


THERMOGRAPHY

Thermography is a touchless imaging method based on the visualization of heat transfer processes. A suitable camera can detect infrared radiation (which is invisible to the human eye) on the surface of the rotor blade. Ideally, the heat transfer processes take place organically without the need to activate them artificially (e.g., during field operation: when a rotor blade, which has been heated by sun radiation during the day, is in heat exchange with the ambient air, which has already cooled down at the end of a day; during production: when the rotor blade shell cools down after curing of the polymer matrix). Heat flow processes within the rotor blade structure are influenced by irregularities within the material (e.g., delaminations, defects in the web bonding, etc.), which in turn affects the infrared radiation at the blade surface. Making this radiation on the surface of the rotor blade visible through thermography enables evaluation of discontinuities which can then be correlated to defects lying below the surface. The correlatability of the observed deviations in the thermal radiation to an exact qualitative and quantitative description of the detected defect, however, drops with decreasing size and increasing distance of the defect from the surface ("depth", in which the defect is located). In general, thermography as a non-destructive testing method provides the advantage that it is contactless and can be used over longer distances. Moreover, it offers the potential to detect defects and damage lying below the surface. However, the resolution is limited, and the evaluation leaves ample room for interpretation and requires experience and accurate knowledge of the boundary conditions, including the blade's structural lay-up.

SHEAROGRAPHY

Shearography is an optical technique that relies on the interference of laser speckle patterns to visualize variations in surface strain. Since it provides full-field measurements and is remarkably robust against external vibrations, it is well suited to industrial non-destructive testing. Shearography measures the changes in surface deformation resulting from two different load conditions (e.g., no deformation vs. mechanically deformed). Evaluating irregularities of the surface deformation enables conclusions about defects on and below the surface. Even small defects, such as delaminations, air inclusions and wrinkles, are detectable. However, the method only works on optically rough surfaces (surface roughness ≥ wavelength of laser). In addition, to create a basis for the measurement, the generation of a "deformed state" is required. Occasionally, this deformation is thermally induced, for instance, through irradiation with infrared radiators. The uniform use of shearography on composite components is supported by international standards, such as ASTM E 2581.



ULTRASONIC TESTING (UT)

The inspection of load-bearing elements of rotor blades by ultrasonic testing as part of quality control has become standard and is widely used in blade manufacturing. UT inspection is based on ultrasonic waves coupled into the inspected structure and their reflection at interfaces. UT-inspections can detect a broad range of defects, from delaminations and defects in bond lines to waves and wrinkles in the fibers of load-bearing elements. The method is widely known in the medical field as a diagnostic procedure (sonography).

The first UT devices for non-destructive material testing were developed in Germany in the 1940s. While the convenience of today's modern UT equipment allows for mobile and flexible procedures, and rotor blade's main load-carrying structures often undergo either semi or fully automated UT scanning in post-manufacturing inspection, expert knowledge and a great deal of experience (analogous to the medical field) is required to interpret the measurements. UT inspections are generally only performed by certified staff, which is a testament to the stringent requirements they need to follow. For example, according to ISO 9712, a level 2 certification as a UT inspector requires a multi-day training course, in addition to several crucial months of inspection experience. Even so, the resolution is limited, preventing very small defects (mm range) from being identified definitively.

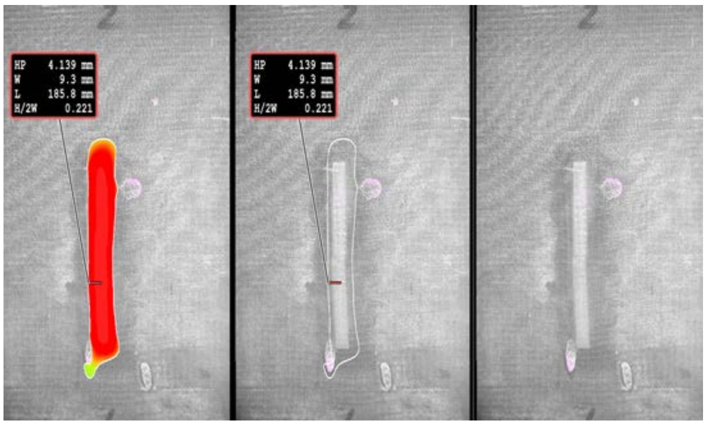
EXPERT INSPECTION

Inspection of rotor blades by experienced experts, supported by non-digital tools like torches, steel ruler, caliper and contour gage has been state of the art for a long time. In the last 20 years, we have seen more rotor blade inspections supported by various non-destructive testing methods. But even today, visual inspection, completed by measuring, raying by torch, and tapping the blade surface, plays an important role. Even in the 2020s, it is nearly impossible to comprehensively inspect a rotor blade without relying upon the knowledge of an experienced expert in that field. This truth is even more apparent when it comes to rotor blades mounted to turbines in the field, where blade accessibility is complicated and sometimes limits the ability to use sophisticated technology. Through increased use of inspection robots and drones, these challenges will obviously dissipate. In the end, the final judgment regarding a defect's severity and need for repair is in the hand of a single or team of experienced technical experts.

OPTICAL SURFACE INSPECTION

For more than 20 years, Optical 3D scanners have been an integral part of quality control in the automotive and aviation industry. Nowadays, optical 3D scanners are also used in the wind turbine rotor blade industry, where they increasingly complement and replace traditional manual measuring equipment. SLI (structured light illumination) is a widely used technology. A structured pattern is projected onto the scanned surface and captured by a camera from a different angle. High measuring speeds (<< 1s), resolutions and accuracies (millions of measuring points and accuracies in µm-magnitude) are characteristics of the method. Because the physics of the measurement principle restricts the analysis of defects hidden in deeper layers, only artifacts and defects visible on the surface can be measured. Moreover, scanned surfaces must neither be extremely specular nor light-transmissive. In such cases, the surface may require pre-treatment to enable scanning.

Optical 3D surface scanning provides outstanding capabilities to reproducibly and accurately measure defects or features on surfaces such as waviness, wrinkles, steps, gaps, chamfers, radii, etc. Today, intuitive user interfaces and software make 3D scanners very user-friendly and require a low level of training.



	EASE OF USE/ FLEXIBILITY	SUITABILITY FOR DEFECTS BELOW SURFACE	RESOLUTION	REQUIRED OPERATOR TRAINING	REQUIRED EVALUATION EFFFORT
THERMOGRAPHY	+	+	-	-	-
UT INSPECTION	-	++	+	--	-
SHEAROGRAPHY	--	+	+	-	-
OPTICAL SCANNING	++	--	++	++	+
EXPERT INSPECTION	++	+	O	--	O

VERY HIGH/HIGH · GOOD/ACCEPTABLE · POOR/INAPROPRIATE · BAD/NOT POSSIBLE · NOT APPLICABLE

TRENDS

Of course, there is a strong trend towards automized data processing when evaluating the condition of wind turbine blades. Algorithms and AI-based systems analyze data harvested from blade inspections to find patterns correlated to certain defects or damage. This process leads to increased objectivity and requires less dependence on the availability of expert knowledge. Experienced wind blade experts are a scarce and, therefore, costly resource.
The inspection itself is also more often performed by drones and robots that autonomously find their way to photograph or scan entire blades without requiring any human interference. This applies to both the in-field and manufacturing environment.
Another aspect is permanent condition monitoring of rotor blades by integrated sensors and the real-time evaluation of their signals. Condition monitoring aims to enable preventive maintenance and repair to avoid severe secondary damage, leading to enormous costs and downtime of the entire WTG system.

CONCLUSION

When it comes to inspection technology, there is no swiss army knife. Instead, to comprehensively evaluate a wind turbine blade's condition, an intelligent combination of different tools and technologies is needed. Yet, even as automated image processing and artificial intelligence grow in popularity, there is no replacement for experienced experts when it comes to more complex technical matters.

“Our vision is to scan and evaluate surfaces in industrial contexts as easily and quickly as shooting a photo.”

ERIK KLAAS

Erik Klaas has more than 30 years of experience in R&D of optical 3D scanners. He holds a degree in optical metrology and led R&D at German 3D scanner cooperation Breuckmann GmbH before founding 8tree in 2012, together with Arun Chhabra. 8tree focuses on application-specific 3D scanners. “Our vision is to scan and evaluate surfaces in industrial contexts as easily and quickly as shooting a photo with a smartphone. Some years ago, we started dealing with quality issues of wind turbine blades. We learned that for comprehensive evaluation of wind blade quality, a combination of multiple inspection technologies is required. We also discovered there had been little evolution over the last 30 years regarding problems that are visible on the surface.

Even in 2021, we have seen widespread use of non-digital, manual measurement tools such as contour gages, calipers, and steel rulers. Against this backdrop, we developed waveCHECK, our latest innovation which measures and evaluates application-specific surface problems within seconds, all at the push of a button. A second feature reports and stores the measurement instantly in our customer‘s ERP system, ensuring more accurate and comprehensively documented results in far less time. waveCHECK’s end-to-end digital workflow not only saves time and money; it also unleashes resources in quality assurance, thus contributing to better overall product quality.”

"It will only be a few years from now, before traditional measurement tools disappear."

JOHANNES GEORG LEIB

Johannes Georg Leib has been working with wind blades since 2008, when he joined Germanischer Lloyd as an authorized expert for fiber reinforced plastic composite materials. Later, Johannes worked as a Global Technical Program Manager for TPI Composites, one of the world's leading wind blade manufacturers. He holds a master's degree in mechanical engineering and plastics processing. In Johannes' view, the digitalization of measurements and the corresponding workflows related to wind blades are not some kind of fancy feature but simply a technical and commercial imperative to keep up with rapidly changing manufacturing and operation environments in an increasingly data-driven world. "It will only be a few years from now, before traditional measurement tools such as calipers and steel rulers disappear from the world's wind blade production shopfloors and the tool kits of blade inspectors and maintenance technicians", says Johannes.

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