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Thermographic inspection of wind turbine rotor blade segment utilizing natural conditions as excitation source, Part II: The effect of climatic conditions on thermographic inspections – A long term outdoor experiment

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ABSTRACT

The present study continues the work described in part I of this paper in evaluating a long-term-experiment, where a rotor blade segment of a wind turbine is exposed to the elements and thereby monitored with passive thermography. First, it is investigated whether subsurface features in rotor blades – mainly made of GFRP – can generally be detected with thermography from greater distances under favorable conditions. The suitability of the sun for acting as a heat source in applying active thermography has been tested in the previous study. In this study, the climatic influence on thermographic measurement is evaluated. It is demonstrated that there are favorable and unfavorable circumstances for imaging thermal contrasts which reflect inner structures and other subsurface features like potential defects. It turns out that solar radiation serves as a very effective heat source, but not at all times of day. Other environmental influences such as diurnal temperature variations also create temperature contrasts that permit conclusions on subsurface features. Particular scenarios are reconstructed with FEM-simulations in order to gain deeper insight into the driving mechanisms that produce the observed thermal contrasts. These investigations may help planning useful outdoor operations for inspecting rotor blades with thermography.

1. Introduction

In the first part I [9] of this study, it was outlined that novel Non-Destructive-Testing (NDT) methods for inspecting wind turbine rotor blades from greater distances are being sought – especially for offshore turbines that are not easily accessible. Conventional inspection methods such as coin tap tests are difficult and dangerous to apply in a rough offshore environment, thus a technology is desired that allows inspections of large pieces without human intervention. In the framework of the research project IKARUS it was investigated whether thermographic methods are suitable for inspecting the condition of (offshore) rotor blades from greater distances, such as from the ground, air-craft or ship – i.e. from distances greater than only a few meters.

Concerning the desired setup from greater distances and the large size of the investigated object, conventional heating sources of active thermography (e.g. flashes, laser, or infrared heaters) are difficult to apply to mounted large-scale wind turbine blades – especially when they are in operation. Therefore, natural heating sources like sunlight, or the diurnal variation of air temperature, and also other natural environmental conditions need to be evaluated.

In part I of this study [9], the ability to use the sun as a heating source for detecting deeper features in Glass-Fiber-Reinforced-Plastics (GFRP) with active thermography has been shown and proven (a scenario that was referred to as "solar thermography"). Furthermore, the operating principle has been demonstrated to be applicable under ideal conditions to a real rotor blade segment mainly made of GFRP. For constituting a more realistic scenario in this part of the study, the IR-camera is now located in a greater distance from a slightly inclined viewing position. The rotor blade segment "ROBAS" was then passively monitored by thermography during different times of day, seasons and weather conditions to evaluate favorable conditions for monitoring. This investigation is crucial for planning a useful thermographic outdoor inspection operation.

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Meinlschmidt and Aderhold [7] suggested several potential applications for a thermographic inspection of rotor blades, including passive thermography on rotor blades on-site. Using passive thermography on a dismounted blade, at a specific time they observed thermal contrasts associated with frozen water inside a blade. Also other thermal contrasts associated with important structures were observed, such as the gluing of the trailing edge. However, so far there are no published results about the environmental conditions, under which these structures can be observed.

A thermographic long-term outdoor experiment has been presented before by [1], who presented a thermal monitoring system consisting of an infrared camera and a weather station to investigate partly defective concrete beams. They demonstrated certain correlations between the concrete's surface temperature and meteorological parameters. Their research focused on the development of system, thus, no investigation is yet evaluated concerning the environmental conditions in detail that may lead to the detection of thermal contrasts and identification of structural or defective elements. That is subject of this study focusing on the rotor blade segment ROBAS which is mainly made of GFRP.

The technical description of the specimen ROBAS and details on the construction of its most prominent features using the numerical FEM-simulation software Comsol Multiphysics 4.4 have been thoroughly introduced in part I and will be referred to in this paper.

First of all, in Section 2, the experimental setup for constituting a more realistic scenario is described and an overview is provided concerning the different environmental conditions under which ROBAS was monitored. In Section 3, variations of the parameter settings in the 3D-simulation are discussed. The simulations serve for gaining a deeper insight into features observed in the thermograms of the long-term experiment, which will be discussed in Section 4 with the thermograms recorded throughout the year under different conditions. Section 5 concludes the most important findings and provides an outlook for further applications.

2. Experimental setup and overview of investigated meteorological conditions

The defective rotor blade segment ROBAS is described in detail in part I [9]. A few prominent features of ROBAS are summarized here as they will be often observed in the following thermograms:

- Beam inside the GFRP shell
- Crack at the leading edge
- Artificial gluing flaws within the trailing edge
- A huge "Tonfa"-shaped anomaly possibly associated with a delamination
- Emissivity contrasts (dirt) on the surface

For creating a realistic setup which would account for an on-site inspection mission of an aircraft or vessel of ground-based team, ROBAS was monitored with a commercially available IR-camera placed on the third floor of a neighboring house 34 m (line of sight) away as illustrated in Fig. 1. The IR-camera (bolometer camera specified in part I [9]) in this experiment was equipped with a 75 mm lens leading to a spatial resolution of 12 mm/pixel.

For investigating the influence of diurnal temperature changes and climatic impact on thermographic inspections, ROBAS was monitored during different weather conditions throughout the year. Particular representative scenarios were chosen that are outlined in Table 1. Detailed weather information during the chosen scenarios was kindly provided by the weather station very close to ROBAS in Berlin-Dahlem of the Meteorological Institute of the Free University of Berlin. The weather station recorded:

- air temperature (measured 2 m above the ground every 10 min),
- relative humidity of the air (measured 2 m above the ground every 10 min),
- diffuse global solar radiation (every 10 min), and
- cloud coverage (hourly).

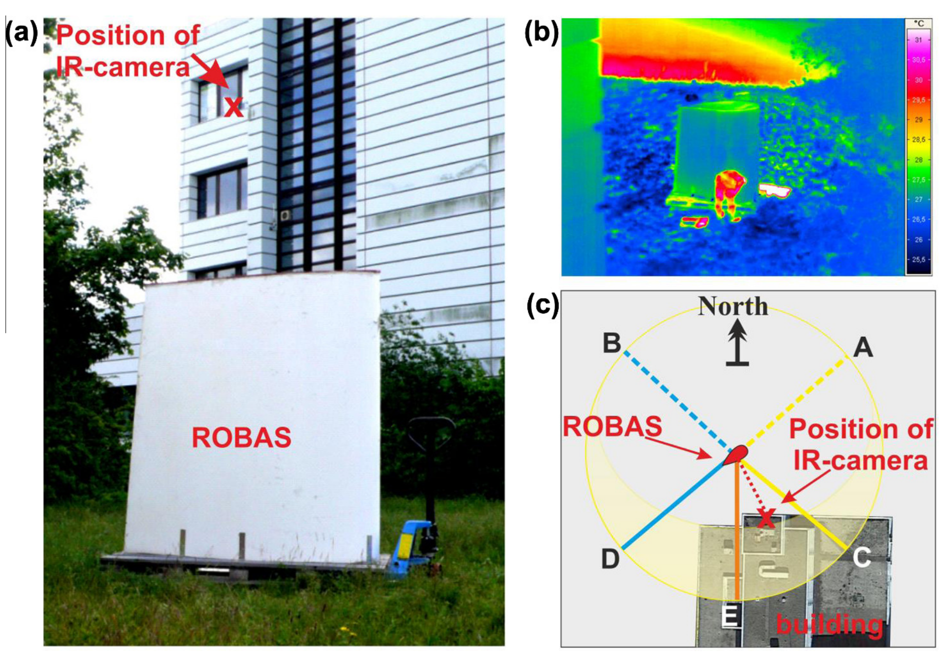

Fig. 1. Experimental setup. (a) Photo from the ground. (b) Thermogram of ROBAS and a person in front recorded with the IR-camera (in the adjacent building's third floor) equipped with a 75 mm lens. (c) Map with sketch of sun positions for different dates: A and B with dashed yellow and dashed blue lines denote sun positions on 26th of June 2013 at sunrise (4:46 am) and at sunset (9:34 pm), respectively; C and D with solid yellow and solid blue lines denote sun positions on 23rd of December 2013 at sunrise (8:18 am) and sunset (3:58 pm); E with solid orange line denotes position at solar noon. Distance between ROBAS and IR-camera is 34 m (marked by red dotted line). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)