Effects of Environmental Influences on Active Thermography to Detect the Inner Structures of Wind Turbine Rotor Blades

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***Abstract*—this work deals with the environmental effects that could influence the active thermographic inspection of the inner structures of wind turbine rotor blades. The transmission of the atmosphere and the impact of wind currents are the main subjects in this study and will be examined through several experiments. The results of these experiments will be processed and their consequences on the method will be presented.**

***Keywords*— Environmental influences; Condition monitoring; Wind energy; Preventive maintenance; Infrared imaging**

I. Introduction

In previous work, Fey et al [2] proved the general feasibility of the active thermography method to detect the inner structures of wind turbine rotor blades. It also was shown that the infrared wavelength of the thermographic camera is not relevant for the general feasibility of the method. Schwahlen et al [5] tested this method in field. Their study shows that the method could be used in on-site test. Some changes in the experiment had to be made to cope with the difficulties in field. However, in the end both setups produced significant comparable results. Further studies from Nieß et al [6] deal with damage that can occur inside of a rotor blade. Damage was categorized by [1] [3] and [4]. The work of [6] further expand these existing categories.

To strengthen the validity of the on-site thermographic tests, the effect of environmental influences must be examined, so that possible failure of the inspection can be prevented, resulting in a robust way of using the save and objective infrared thermography to inspect wind turbine rotor blades compared to the commonly used inspections.

II. Fundamentals

A. Infrared atmospheric window

The infrared atmospheric window (Figure 1) shows in which band the atmosphere has the highest transmissivity [7]. Farther, the figure points out which molecules absorb the radiation. The used camera captures the wavelength range of approximately nine µm. As can be seen the two gases aqueous vapor (H_2O) and carbon dioxide (CO_2) are the primary concern for absorbing the infrared radiation. This leads to the assumption that the recordings can be influenced through these gases.

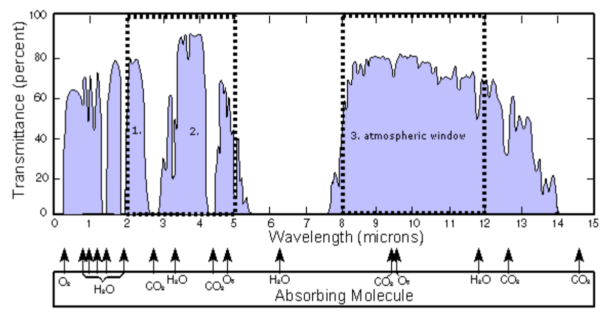

Figure 1. Atmospheric window [This work is licensed under a Creative Commons Public Domain Mark 1.0 License]

B. Wind currents on the rotor blade surface

On some of the thermographic images, structures can be recognized which cannot be assigned to the inner structure of the rotor blade (Figure 2). One theory is that wind currents are responsible for these unexpected patterns. They should cause a relative temperature difference on parts of the blades surface and thus show differences in the infrared images. It remains to be seen whether this assumption is confirmed or whether the structures on the rotor blade have another still unknown origin.

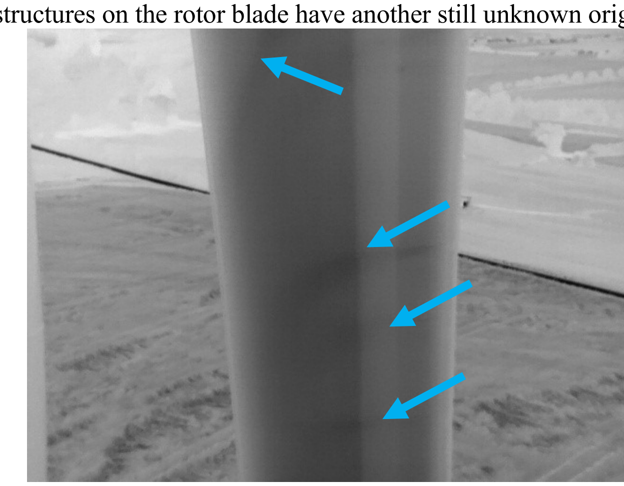

Figure 2. wind currents on the blades surface

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III. TEST SETUPS

The fundamental test setup is the same for all experiments in this study. The infrared camera, FLIR A655sc, is placed approximately 5 m in front of the rotor blade specimen. It is an uncooled micro bolometer with a spectral range of 7.5 – 14 µm and 640 x 480 pixel resolution. The distance of 5 m is realistic even in the field, where the camera will be flown up by drone.

For this procedure only the temperature difference is important and not the real temperature of the blade. The wavelengths in the thermographic recordings can deviate from the expected values, since the camera sensor makes a record that watches integrated over the entire wavelength band.

The IR lamp Trotec IR S2550 is used to heat up the blade with a heating capacity of 2500W. The IR lamp is positioned approximately 1m in front of the rotor blade. It can be controlled remotely and provides the opportunity to be turned off by timer. The heating and cooling times for these experiments will be set at 30 minutes. This time span proved to be optimal in previous tests.

A. *Relative humidity*

The setup for the experiments on relative humidity needed some special preparations. Therefore, a room in which the relative humidity can be manually controlled had to be created.

To achieve this appropriate experiment environment a greenhouse was customized (Figure 3).

To change the relative humidity inside the experimental environment a humidifier was used. It has an integrated hygrometer to track the relative humidity. This humidifier is fit to damp rooms up to the size of 60 m², which is sufficient for the used green house.

The infrared camera, FLIR A655sc that operates in the longwave infrared spectrum recorded the up heating and down cooling process of the specimen.

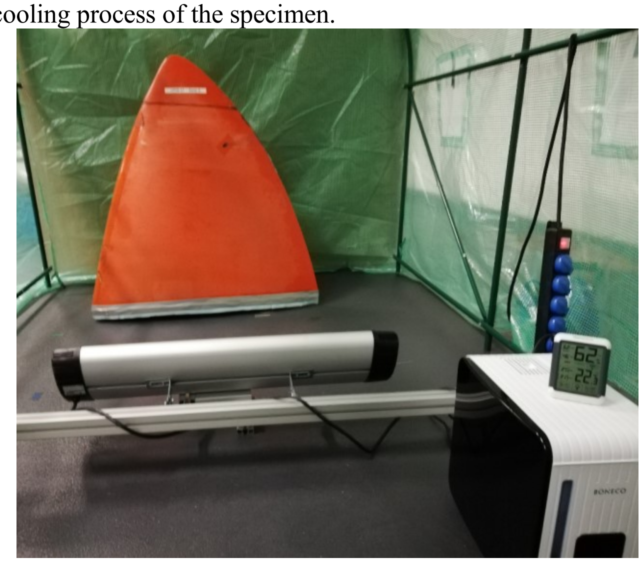

Figure 3. Test setup relative humidity; rotor blade specimen HRW01 – rotor blade tip

1) *Condensation*

Since a relative humidity over 100 percent results in condensation, a second approach to test the influence of high humidity was made: With an atomizer, the rotor blade was humidified while making a thermographic recording [2]. This should emulate condensation at the specimen's surface. This would be the case if the relative humidity exceeded 100 %.

B. *Wind currents*

Some slight adjustments had to be made to perform the test series of wind influence to the heating and cooling process of the blade (Figure 4).

Figure 4. Wind test setup: rotor blade specimen HRW00

A drum fan (DF800 Casa Fan) was used to generate an irregular stream of air. An excerpt of its specification can be found in the following table (Table I).

TABLE I. TECHNICAL DATA DF800 CASA FAN

Basket Ø (mm)	790
Wing Ø (mm)	750
Power engine (W)	123
Voltage (V/Hz)	220-240/~50
Number of revolutions (U/min)	870
Airflow (m³/h)	15650
Flow velocity on the blade(m/s)	Stage 1: ~5 Stage 2: ~6

During the wind test, the fan was placed to the side of the rotor blade at a distance of 1m. During the heating and cooling periods, a steady wind coming from a fixed direction with wind speeds between 1.4 and 3.8 m/s was generated.

IV. RESULTS

A. *Realtive humidity*

In the recorded infrared images (Figures 7 and 8), no significant differences can be detected. The temperature curves (Figures 5 and 6) do not allow conclusions to be drawn about a worse feature recognition.

At the recording distance of 4.5 m, no influences from increased relative humidity in the long-wave infrared range were detected.

The medium wave infrared range was not considered in this test series. However, it has already become apparent from earlier test series that the quality of the recordings does not differ [2].

A detailed analysis of the curves and recordings shall be done in the following. For the displayed measurement curves, areas in the thermographic recording were evaluated which represent the different materials of the blade.

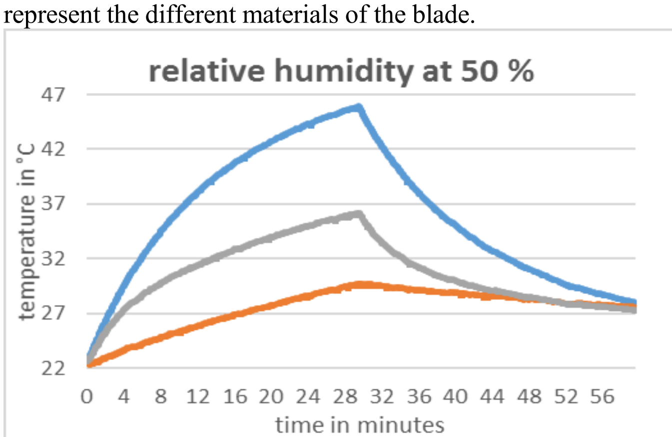

Figure 5. Relative humidity at 50 % [blue: balsa wood; grey: adhesive; orange: tip of the blade]

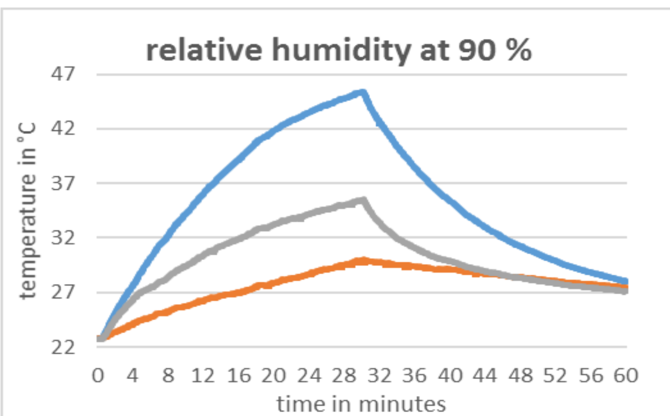

Figure 6. Relative humidity at 90 % [blue: balsa wood; grey: adhesive; orange: tip of the blade]

Figures 5 and 6 show temperature curves of the heating and cooling process at a relative humidity of 50 % and 90 %, respectively. In a comparison of the two graphs, there are no noticeable differences in both heating and cooling.

From the two temperature curves, it can be seen that the different materials inside the blade offer an optimal contrast at minute 32 in both measurements.

For this reason, the thermographic recording at this time stamp was examined in more detail. Figures 7 and 8 show the tip of the rotor blade at the specified time. If compared the two images show no significant difference in the features of the rotor blade, as confirmed by their temperature graphs.

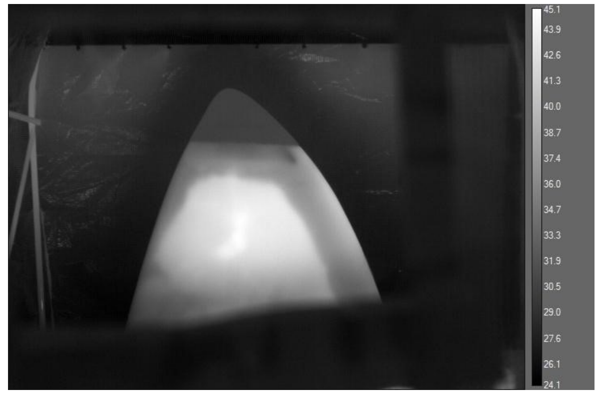

Figure 7. Rotor blade specimen HRW01 minute 32; 50% relative humidity

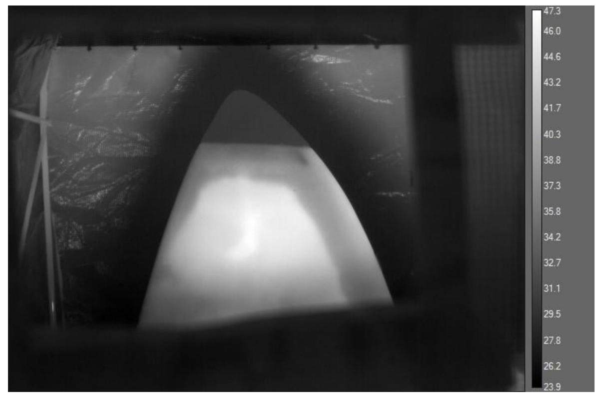

Figure 8. Rotor blade specimen HRW01 minute 32; 90% relative humidity

The theory suggests that interference from atmospheric influences, such as aqueous vapor (H_2O), is to be expected. However, these could not be determined for a relative humidity below 100 %.

It remains to be determined if wet conditions on the rotor blade influence the thermographic inspection.

1) Condensation

For this purpose, the rotor blade HRW00 is moisturized an atomizer in a separate test. This is supposed to imitate the effect that dew has formed on the rotor blade. The remaining test setup is not changed.

Figure 9. Timestamp t1 - right after humidifying the specimen

At first, the water on the surface does not cause the expected information losses in the recording (Figure 9). However, several minutes after humidifying the blades surface the vapor merges into drops of water, which effects the recording significantly as it can be seen in Figure 10.

Critical information get lost so that it is no longer possible to make a qualified statement about the inner structures status.

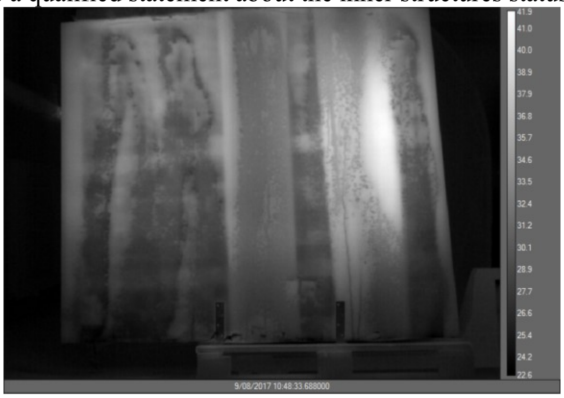

Figure 10. Timestamp t2 - several minutes in the down cooling process

It can be said that at a relative humidity above 100 % interference can occur when water forms on the rotor blade. However, at a relative humidity below 100 %, no difference can be noticed in the recordings. This shows that a dry wind turbine rotor blade can be thermographically inspected without losses.

B. Wind currents

At first, a comparative experiment was made without disturbances from the environment. This experiment should be used as a comparison in the evaluation of results.

In the comparative test, the internal structures of the HRW00 rotor blade become visible as usual (Figure 11).

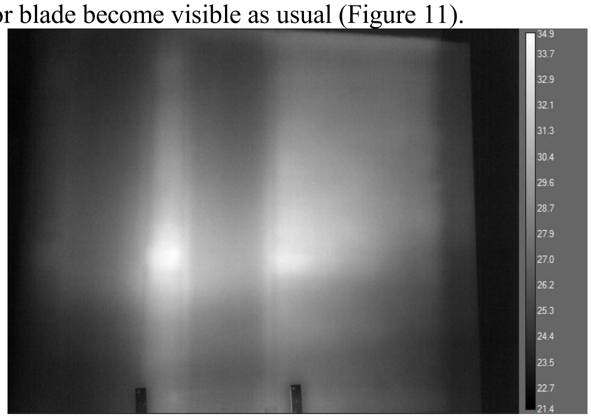

Figure 11. Comparative experiment: fan switched off [minute 40]

In the corresponding temperature curve (Figure 12), it can be seen that the temperatures of the different materials differ most strongly from each other in minute 40. This is the indicator that the optimal temperature difference and therefore the best contrast in the infrared recording allows the optimal feature recognition inside the rotor blade. The recording at the specified measurement time is shown in Figure 11.

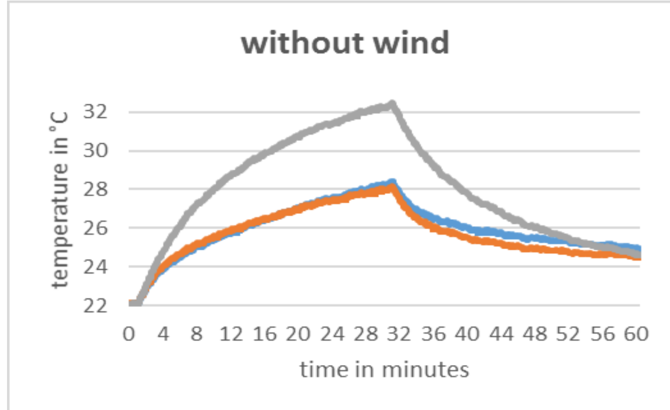

Figure 12. Temperature curve fan switched off [blue: spar cap; grey: balsa wood; orange: adhesive]

The thermographic image and the corresponding temperature curve of the first test in which the fan was active are examined below. Wind speeds of up to 2.8 m/s could be measured on the first stage of the fan, which was installed at a distance of 1m from the blade. How this wind force has propagated on the thermographic image can be seen in Figure 13.

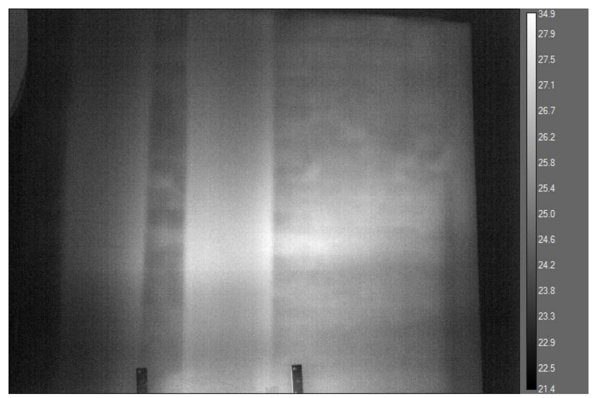

Figure 13. Wind speed of 2.8 m/s [minute 40]

The HRW00 test rotor blade is visibly warmed up on the part where the fan is directed, but not as quickly as in the comparative test. This can be seen in the darker image on the left side of the rotor blade.

The temperature curve (Figure 14) of this image shows that the various materials in the rotor are not as high in temperature as in the comparative test. However, they cool down faster. It can also be observed that the adhesive and the spar cap no longer differ sufficiently in temperature and can therefore not be distinguished in the thermal recording (Figure 13).

Figure 16 shows the rotor blade HRW 00 in another test. The wind speed was increased up to 3.86 m/s. Just like before, it shows that the side to which the fan is directed does not heat up as fast as the rest but the rotor blade cools down faster overall.

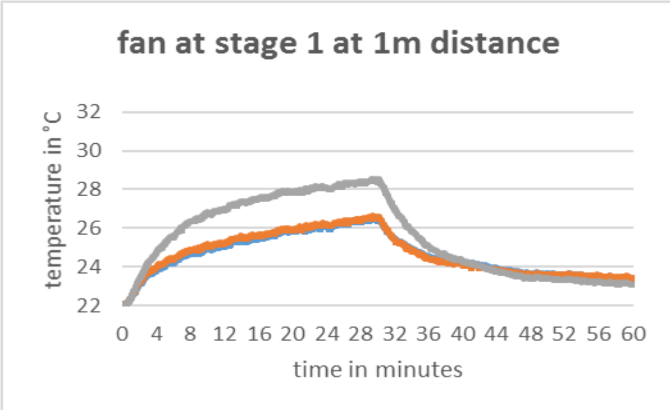

Figure 14. Wind speed of 2.8 m/s [blue: spar cap; grey: balsa wood; orange: adhesive]

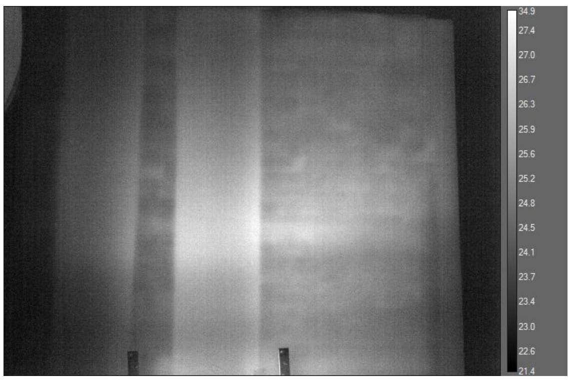

Figure 15. Wind speed of 3.86 m/s [minute 40]

If the temperature curve over time (Figure 16) is compared to the curve in Figure 14, it turns out that the two curves hardly differ at all. This conspicuousness could also be reproduced in further tests. As a result, it is concluded that this will also occur at higher wind speeds. In order to compensate for this effect, a stronger energy source is needed to heat up the wind energy rotor blade. Such a heat source is given in the field by the sun, however, in order to exclude that this effect in the field has no influence on the meaningfulness of the images; further tests must be carried out.

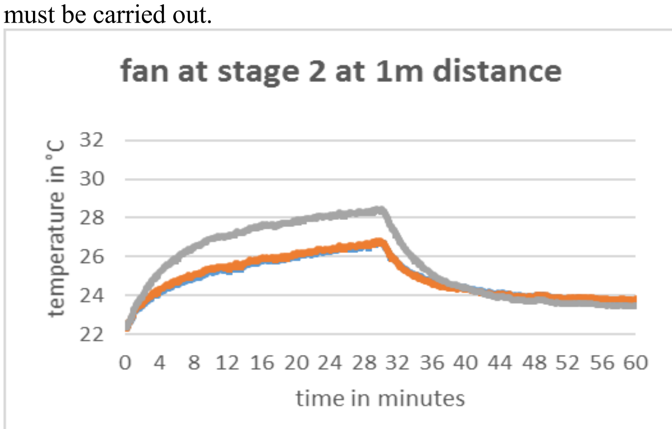

Figure 16. Wind speed of 3.86 m/s [blue: spar cap; grey: balsa wood; orange: adhesive]

V. CONCLUSION

It was found that a relative humidity below 100 % has no significant effect on the thermographic inspection of the wind turbine rotor blade. Furthermore, it was found that when the rotor is wet (relative humidity > 100 %) the results of the inspection are strongly influenced and therefore no conclusions can be drawn about the internal structures of the rotor blade.

The recording series did not show how the atmospheric effects of H_2O affect the thermographic images when the recording distance becomes significantly higher.

Through the test series, which was to show the influence of wind on the inspection, the following findings could be obtained: The structures shown in Figure 2 did not appear in the form in the images of this test series. Therefore, it remains to confirm whether these were caused by the wind. This experiment showed that the different materials of the rotor blade, with a constant heat output of 2500 W, no longer differ sufficiently in temperature. Therefore, the contrasts in the infrared image no longer become visible and allow fewer statements about the inner structures.

It remains to be checked whether this observation can be confirmed with a more powerful heat source (> 2500W) and therefore a more efficient up heating of the blade.

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