Thermographic Inspection of Rotor Blades

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Abstract. This article describes the principle technique of passive and active thermography. In detail the more advanced technique of online heat flow measurements especially for the inspection of rotor blades are explained. Many examples show the possibility to detect defects like poor bonding, delaminations and internal structural faults by using passive techniques. But more advanced techniques like active online thermography will demonstrate the outstanding results in finding even small defects in these up to 65 m long rotor blades of wind turbines.

Introduction

The rotor blade is the most important part of a wind energy plant. It is a light weight construction but has to sustain heavy wind loads and harsh environment conditions.
Today, most of the blades are made of two glass fibre reinforced plastic half shells which are glued together. Usually for stiffness reasons, different types of spars are introduced into the blade. These glued joints are the potential defective or weak parts of the construction.

During their lifespan the rotor blades underlie different loads due to gravitational, centrifugal and aerodynamic forces. Due to different stress situations, various kinds of damages can appear e.g. delaminations and cracks. To prevent the damage, the blades have to be inspected regularly, which can be done by non-destructive testing methods.

Beyond the inspection of the manufacturing process, there is an increasing demand for a continuous on site inspection which can be executed either on blades lying on the ground or fixed at the tower.

1. Thermographic Inspection Techniques

Passive thermography is a well known and accepted technique for the detection of defect working parts in the electronic industry or for the discovering of heat losses of houses [1-3].

The specific of passive thermography is the measurement of the heat distribution on the surface without any active impact of additional heat. The infrared-camera (IR-camera) observes during the passive measurement the radiation heat of the surface under inspection. The incident radiation will be converted by the detector into electronic signals and can be displayed as an IR-image on a monitor or can be stored for further image processing on a computer (Fig. 1). Using modern highly sensitive IR-cameras, temperature differences of a few hundreds degree (about 0,015 °C) can be observed and measured.

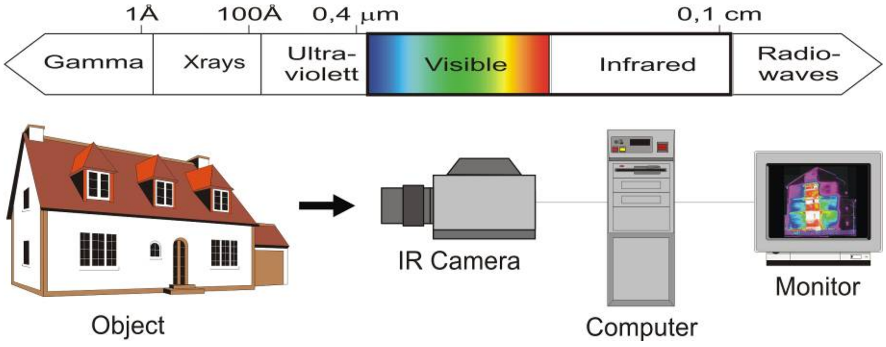

Fig. 1: Image processing setup using an IR-camera to visualize even small temperature differences on the objects surface.

Every IR-camera supplies in the first instance black/white images with a gray-value resolution of 8 to 16 bit. Every value corresponds to a certain temperature value which can be converted into false colors for a better recognition of temperature differences. Usually the red colors are used for visualizing warm regions and green/blue colors for cold regions, corresponding to the human feelings.

In the case of passive online thermography [4-5] the material under inspection is coming hot out of the production process and the different cooling of the surface gives a hint on possible defects within the material. Usually the surfaces above a defect like an air inclusion (good heat insulator) will appear as "cold spot" (Fig. 2), because the heat of the core material can not reach the surface as fast as in an undisturbed material.

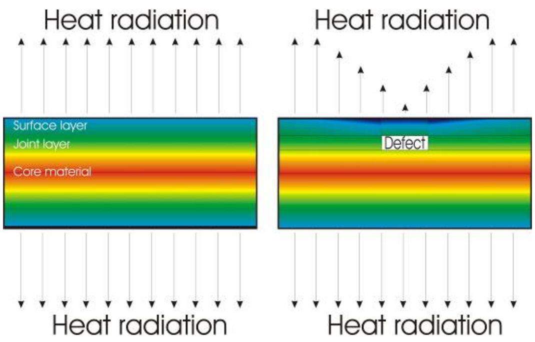

Fig. 2: Principle of the passive online thermography.

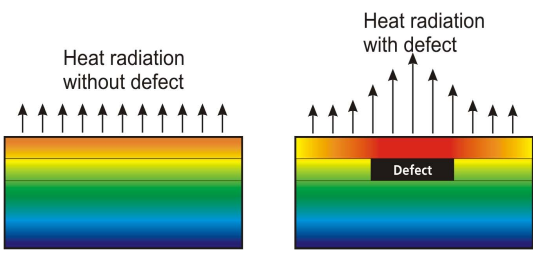

Fig. 3: Principle of the active online thermography.

In the case of active online thermography [6-13] the material will be transported cold and the surface has to be actively heated with radiators. The different cooling of the surface will show possible defects within the material. The surface above an air gap (good heat insulator) will be hotter for a longer time in comparison to its surrounding and it can be observed with an IR-camera as "hot spot" (Fig. 3).

2. Examples of Passive Inspections

Passive thermography (with no additional added energy) can be used in three different stages:

- In the workshop, using the exothermic energy released by the chemical reaction of the two components of the glue
- In the testing area or on the turbine, observing the rotor blades while they have to undergo fast cyclic mechanical loadings
- On site, using the natural environmental conditions like sun and daily climatic changes as driving force.

Example 1:

Observing the rotor blade from inside and outside during or short time after the production process or while repairing, will deliver many information about possible internal defects. Fig. 4 shows the IR-camera during a measurement campaign observing the still hot blade from inside. The thermal image (thermogram) in Fig. 5 (top) shows the temperature distribution within the rotor blade short time after gluing the two separate shells together. Defects which occur during the gluing of the two shells can be observed from outside the blade either in the leading edge (see Fig. 5, bottom) or in the trailing edge.

Fig. 4: Photo showing the passive inspection of the inner part of the rotor blade with an IR-camera.

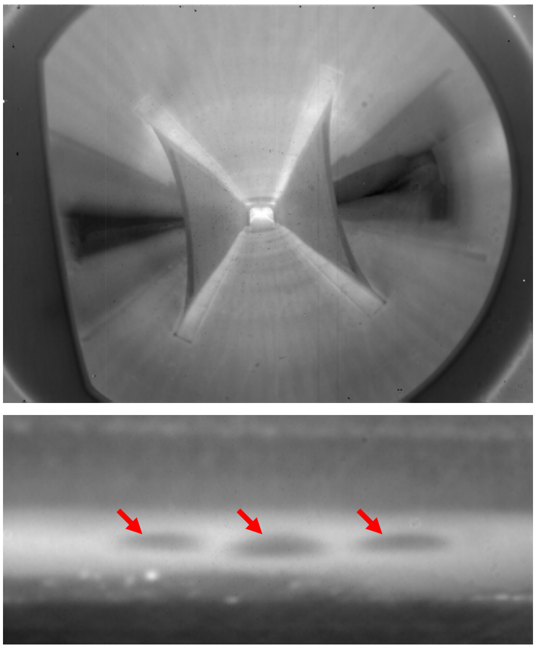

Fig. 5: Thermal image of the rotor blade from inside (top) and defect gluing indexed by red arrows on the leading edge (bottom) observed from outside.

Example 2:

Heavy wind and air pressure changes have a great impact onto the laminated rotor blade material. Especially the continuous influence of cyclic loadings will affect the material, cracks will appear and an ongoing degradation process will affect the blades.

Frequently changing of the loads, will produce temperature differences in the blades during the rotation indicating high stress or stress release in different areas of the blade (Fig. 6).

Beside the stress distribution, small cracks and dry laminate will produce heat by friction due to the cyclic excitation (Fig. 7, red arrows).

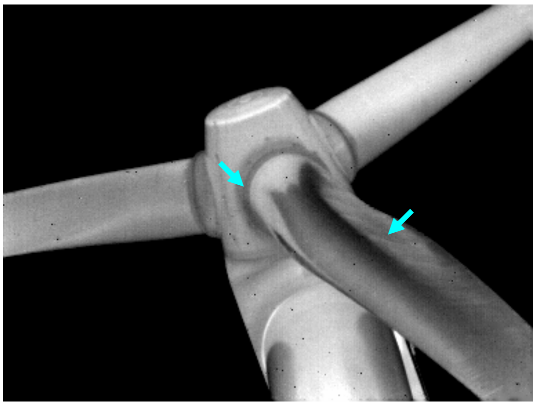

Fig. 6: Thermal image of the rotor while it is moving. The bright areas are warmer as the dark areas and show the heat production due to mechanical loading (blue arrows).

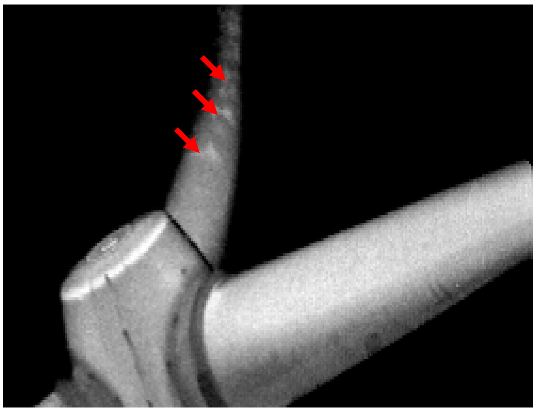

Fig. 7: Thermal image of the rotor while it is moving. The bright areas indicate delaminations produced by heat due to the friction of micro cracks.

Example 3:

Another way to detect defects deeply within the rotor blade is to use the climatic changes or heat differences of the sun illumination. In Germany, the changes in temperature from night to day will reach sometimes more than 20 °C within a few hours.
The surface of the rotor blade which is illuminated directly by the sun will be in wintertime 15 °C - 20 °C hotter than the backside surface. These huge temperature differences can be used to detect not only surface defects but also defects deeply in the blade.

Fig. 8 shows the IR-camera during a cold freezing winter day observing some parts of the rotor blade. Some minutes or hours after sunset, different effects within the blade could be observed (Fig. 9): the frozen water within the tip of the blade (arrows) or the main spar as cold rectangular block on the right side of the thermogram.

Fig. 8: Photo of the IR-camera during the passive inspection of the blade.

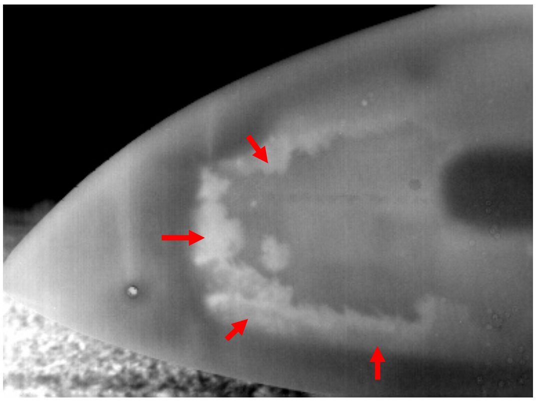

Fig. 9: Long time after sunset, the thermal image of the tip of the rotor blade is showing the frozen water (arrows) inside the blade.

Fig 10 is a panorama view composed of 4 different thermal images taken in a cold winter night, shortly after sunset. Most of the important inner structures of the blades can be seen, as the glued rim at the trailing edge indicated by the arrows or the twin main spars marked by the rectangle. A repaired area can be seen only very faintly as weak white shadow which is circled for better visibility.

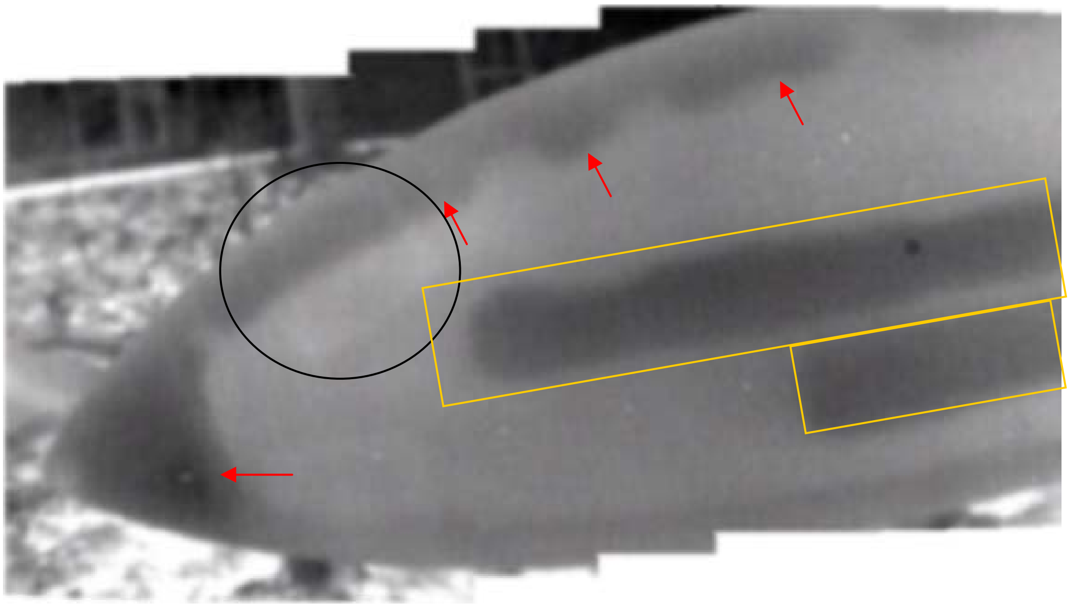

Fig. 10: Thermal image of the rotor blade showing important structures like the gluing at the trailing edge (arrows), the twin main spars (rectangular) and a repaired area (circle).

3. Examples of Active Inspections

The technique of active thermography (with additional added energy) can be used in three different stages [14-16]:

- In the finishing workshop at the producer, using a moveable inspection system on a trail
- In the testing area, using a conveyor belt
- On site -before installation of the rotor blades at the turbine
  -already installed, in the air
  -during reparation while the rotor blades are placed on the ground.

Example 1:

After gluing the two half shells together, the rotor blade has to undergo a finishing work like removing the surplus glue, painting as well as visual and carrying out acoustic inspections. In this stage the acoustic inspection, also called percussion or tapping method for detecting defects, can be replaced by the timesaving online IR-technique. By moving the inspection system on a trail system along the rotor blade (Fig. 11), different types of defects can be detected.

One major defect is the penetration of air during the vacuum injection of the glue. If too much air is introduced into the glass fiber web, the air bubbles (Fig. 12, white areas) will create large areas of weakly bonded laminate.

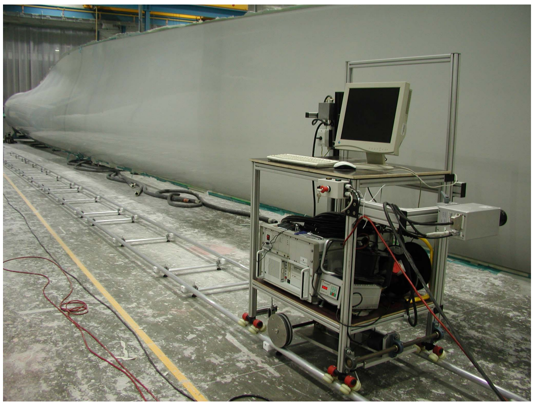

Fig. 11: Active online thermography setup on a trail for the inspection of long structures.

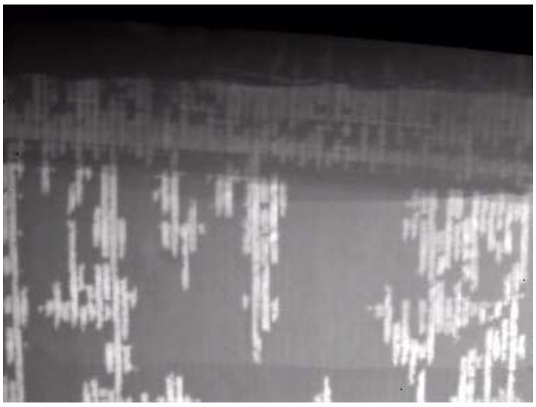

Fig. 12: Extended air bubble inclusions can be detected with online thermography.

Example 2:

Small samples or broken pieces of real rotor blades can be placed on a conveyor belt. By moving the material along an infrared radiator, the surface will be heated gently by a few degrees. Subsequently, the material is moving beneath the IR-camera for thermal inspection (Fig. 13). Defects like delaminations can be seen as hot spots while reinforcements; spars and webs show up as cold areas and fringes (Fig. 14).

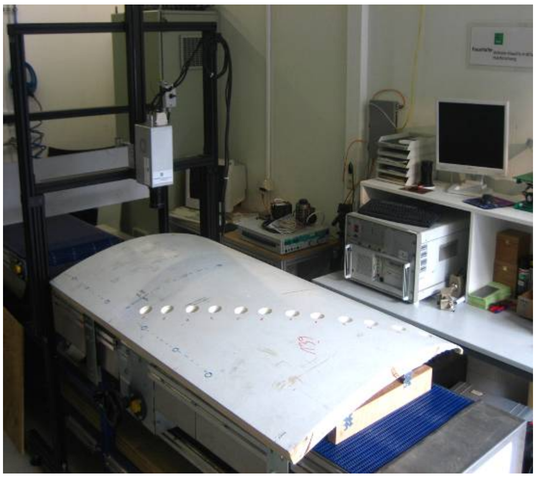

Fig. 13: Laboratory test system on a conveyor.

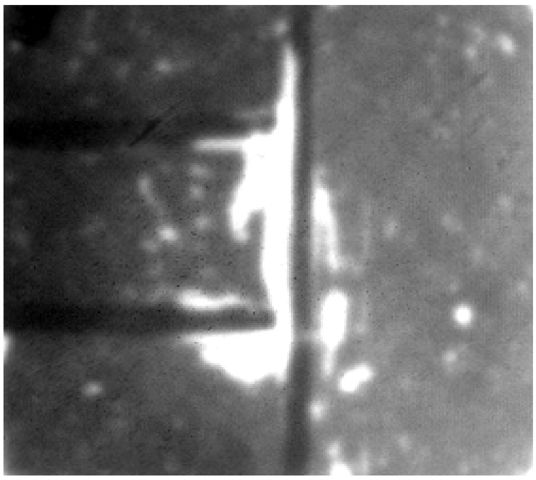

Fig. 14: Thermal image of a test sample showing delaminations as white/hot areas and thin reinforcements as dark fringes.

Example 3.1:

On site measurements are always much more difficult to execute than the tests under laboratory or workshop conditions. One possibility is to do the measurements before the blades are installed at the tower (see Fig. 15). In this case, the glue joint (Fig. 16, left) should be tested from inside for delaminations and large air inclusions. By heating and observing the material from inside the blade, large debonded areas can be seen as white or hot spots (Fig. 16, centre). Whereas transmission tests with the heating source outside and the camera inside show the same debondings inversely as cold spots (Fig. 16, right).

Fig. 15: Photo of a rotor blade which was inspected just before installation.

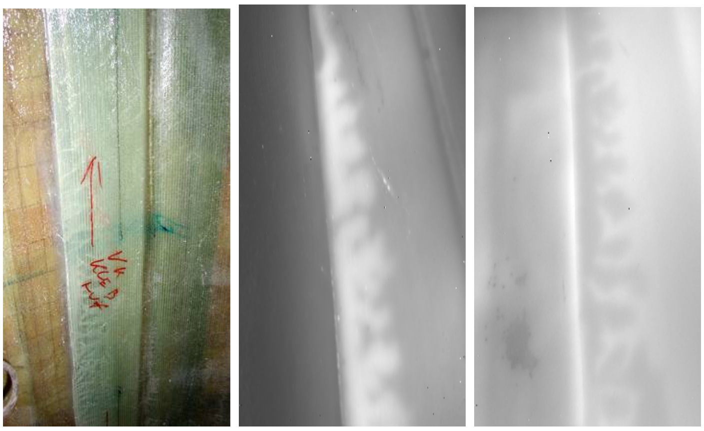

Fig. 16 Photo of a glue joint (left) and thermal images showing the defects (air gaps) in reflection mode (centre) as hot spots or in transmission as cold spots (right).

Example 3.2:

On site measurements in the air at the installed rotor blade are the most difficult work, because of the harsh weather conditions. Wind turbulences, for example, will instantly change the distance between camera and rotor blade, and defocusing will make the thermal images unusable. Nevertheless, it is possible to execute measurements in elevations higher than 100 m (Fig. 17, left). For these tests, the infrared radiator was fixed at the working platform of a so called "cherry picker" and the camera was installed on a tripod (Fig. 17, right). By moving the cherry picker from the shaft to the tip of the rotor blade the surface can be scanned for internal defects.

Fig. 18, left shows a thermal image with clearly visible delaminations on the blade and Fig. 18, right visualized some air bubbles in the trailing edge by hot spots.

Fig. 17: The measurement system fixed at the working platform of the lift (right) and working in a height of about 100 m (left).

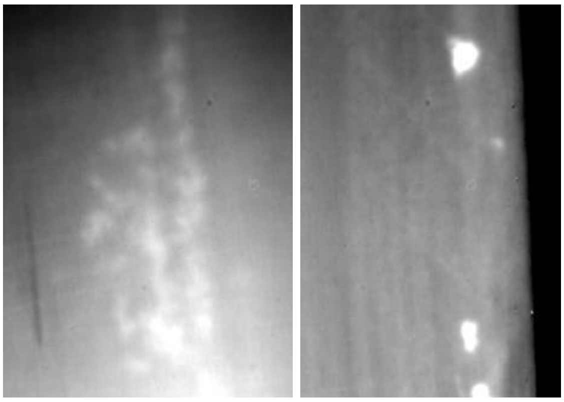

Fig. 18: Thermal images taken from the measurement shown in Fig. 17. Clearly visible are delaminations in the blade (left) and air bubbles in the trailing edge (right).

Example 3.3:

During regular reparation on the gear or while replacing the power generator, the rotor blades are sometimes temporarily moved to the ground. This is usually done by two cranes lifting the three blades as one connected unit to the ground (Fig. 19). During these measurements some manually inspected conspicuous areas could be tested with infrared thermography. In this way, poor bonded glass fiber reinforced material (dry laminate) could be detected as Fig. 20, top shows. Moreover, blocked water drainage could be detected. This can be seen on the two superimposed images in Fig. 20, bottom. The colored photo shows the tip of the rotor blade, where the hand holding the pencil indicates the drilled hole for water drainage. The overlaid thermal image shows the internal structures like the main spar and the glue surplus of leading and trailing edge as well as the glue in the tip. The overlay shows, that the glue is blocking the drainage.

Fig. 19: Removing the three blades from the generator and placing it on the ground.

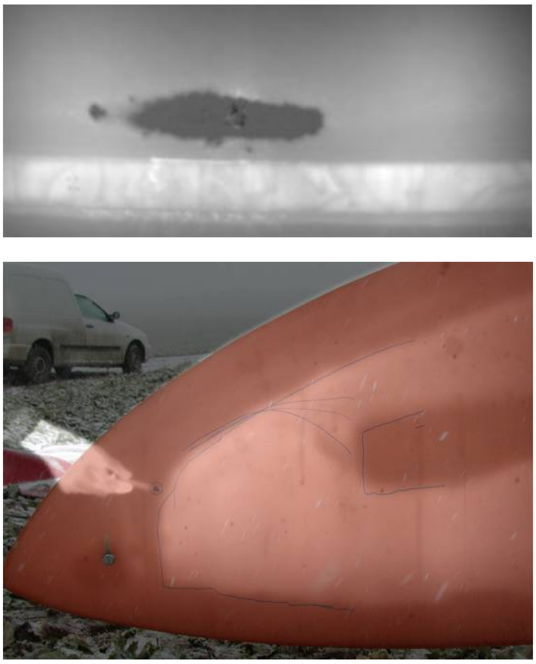

Fig. 20: Thermal images taken from the measurement shown in Fig. 19. Clearly visible are regions with poor bonded glass fiber (top) and missing or blocked water drainage.

3. Conclusion and Perspectives

Passive and active thermography is a powerful technique for the detection of different defects like delaminations, air bubbles, dry glass fiber reinforced and structural faults. This technique can be applied as well in the workshop just after the production or in the field.

Some companies started already to use passive thermography for the detection of extended glue faults in the production. But in future more and more companies will start to inspect every single rotor blade for a 100 % quality assurance. Especially if the blades are used for off shore applications, every single defect has to be found to avoid high consequential costs.

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