

## **Inspection techniques for wind turbine blades using ultrasound and sound waves**

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### **Abstract**

Facing the climate change the use of renewable energies gains in importance. Especially wind energy will play a major role in the power supply in Central Europe. Due to the increasing number of installed wind energy plants, regular inspections are necessary to avoid accidents. Besides the tower and the gear, the wind turbine blades are highly stressed parts. Suitable non-destructive testing techniques for in service inspections have to be developed to replace the simple visual inspection techniques used today.

The techniques described in this paper use ultrasonic waves and sound waves to detect and localize damages within the turbine blades. The pulse echo technique is used to detect flaws in the bonding areas. Several centimeter of GFRP, which highly attenuates sound, have to be penetrated and thickness variations not exceeding 15 mm have to be resolved. A reproducible coupling of the ultrasonic sensors has to be done to compare adjacent measurements. The use of couplants like water or oil is not possible as the blades are very big and large amounts of couplant would have to be carried along during the inspections.

Additionally an enhancement of simple tapping tests, a so-called local resonance spectroscopy, will provide information about the construction design of the turbine blade, which normally is not known exactly and can't be seen from the outside of the blade. Using an impact hammer a sound is excited within the material. A difference in sound can be heard on damaged areas or at material changes. They are recorded using a microphone. Additionally the excitation signals can be recorded, using a force transducer embedded in the impact hammer. It can be shown that the analysis of the excitation signals provides information about structure and health of the material.

The described techniques shall be realized as small and portable systems, so they can be used by evaluaters without the use of expensive cranes. Also the equipment can be linked to automatic inspection systems like robots.

### **Résumé**

Pour faire face au réchauffement climatique, l'utilisation des énergies renouvelables gagne en importance. L'énergie éolienne jouera particulièrement un rôle majeur dans l'approvisionnement en énergie en Europe centrale. En raison de l'augmentation du nombre des centrales éoliennes installées, des contrôles réguliers sont nécessaires pour éviter les accidents. A côté de la tour et du matériel, les pales des éoliennes sont des parties fortement sollicitées. Des essais non destructifs adaptés pour les inspections en service doivent être mis au point pour remplacer la simple inspection visuelle utilisée aujourd'hui.

Les techniques décrites dans le présent document, utilisent des ondes ultrasons et sonores pour détecter et localiser les dégradations à l'intérieur des pales. La technique pulse-écho est utilisée pour détecter des défauts dans les zones de collage. Plusieurs centimètres de PRFV, qui atténuent fortement les sondes, doivent être traversés et les variations d'épaisseur, ne dépassant pas 15 mm, doivent être résolues. Un couplage reproductible des capteurs ultrasoniques doit être fait, pour pouvoir comparer les mesures adjacentes. L'utilisation de couplants comme l'eau ou le pétrole n'est pas possible compte tenu de la grandeur des pales et des grandes quantités de couplage devront être acheminées lors des inspections.

En outre, une amélioration des tests de sonages simples, ce qu'on appelle la spectroscopie des résonances locales, fournira des renseignements sur la construction de la pale, ce qui normalement n'est pas connue exactement et ne peut pas être vu de l'extérieur. Un marteau d'impact est utilisé pour exciter la structure. Une différence dans le son peut être entendue sur les zones endommagées ou à des changements structurels. Le son est enregistré à l'aide d'un microphone. En plus, le signal d'excitation peut être enregistré, à l'aide d'un transducteur de force, qui est couplé au marteau d'impact. Il peut être démontré que l'analyse des signaux d'excitation donne des informations sur la structure et son état de santé. Les techniques décrites sont réalisées avec un appareil petit et portable, de sorte qu'elles peuvent être utilisées l'utilisation de grues chères. Par ailleurs, l'équipement peut être lié à un système d'inspection automatique, comme un robot.

## **Keywords**

Ultrasound-Echo, dry coupling, wind turbine blades, GFRP, local resonance spectroscopy

## **1 Introduction**

In 2008 the European Union decided to reduce greenhouse gases by 20 % and to increase the rate of renewable energies from 6.6 % to 20 % in the EU overall energy consumption by 2020. According to the *Directive on the Promotion of Electricity Produced from Renewable Energy Sources in the Internal* [1] announced by the European Parliament in 2001 the electricity production from renewables shall be raised to 21 % by 2010. The target value for Germany was scheduled to 12.5 % in the Renewable Energies Act (EEG[2]) and was already achieved in 2007. Recently it has been elevated to a 25 to 30 % share until 2020.

In Germany about 40 % of electricity gained by renewable energies is generated by wind power. Therefore Germany takes a leadership role in the investigations in wind energy. More than 18.000 wind energy plants are running at the moment gaining more than 20.000 MW power. Both the highest and the most powerful wind energy plants are running in Germany.

To increase the rate of renewable power sources in the future more and more powerful wind energy plants and wind parks will be built. As people will live nearer to wind turbines the safety of wind power plants will become more and more important. Also the downtimes of wind turbines have to be kept short, as wind energy will become more important to the electricity market.

Nowadays the inspection techniques at wind turbine blades are limited and lack in reproducible inspection techniques. During a so-called InnoNet-Project by the project executing organization VDI/VDE, funded by the German Ministry for Economy and Technology, a combination of techniques using acoustic and electromagnetic waves, will be developed for practical application. The acoustic techniques will be presented in this paper.

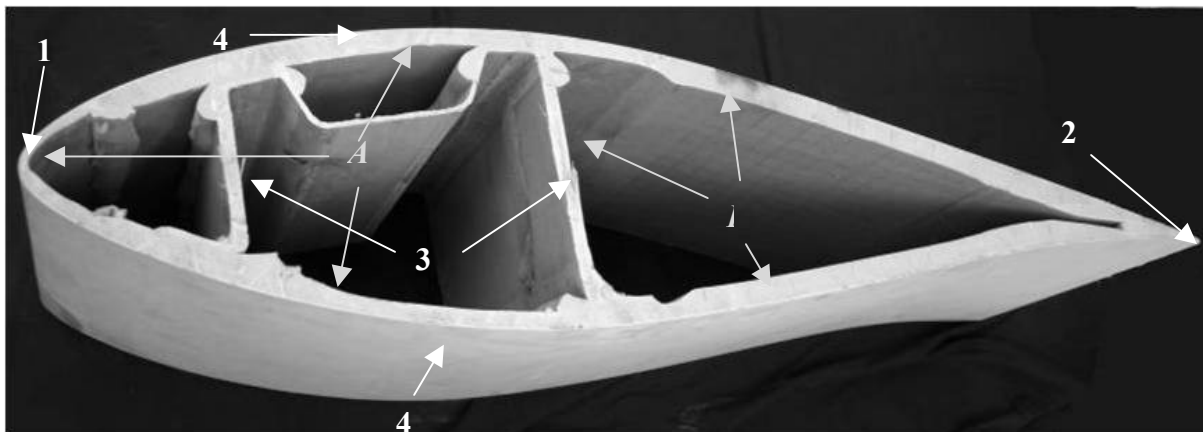
## **2 Wind turbine blades**

In Germany wind energy plants have to be inspected at regular intervals, depending on the size, every two to four years. Besides the tower and the mechanical parts like the gear, the turbine blades are part of these inspections. Due to the constant wind contact the blades are highly stressed parts of the turbine. However the inspections are limited to visual inspections and simple tapping tests. These techniques acquire a high level of experience and are not able to detect internal damages that aren't visible at the surface of the blade. Figure 1 shows an industrial climber roping from the rotor of a wind turbine to inspect critical areas of the blades. Besides the use of basket cranes this is a common way to get access to the blades.



**Figure 1:** Inspection of a wind turbine blade.

Wind turbine blades are mainly built of fiber reinforced plastics and lightweight materials like plastic foam or wood. Glass fiber reinforced plastics (GFRP) are due to the cheaper price preferred to carbon fiber reinforced plastics (CFRP) that are common in aerospace industries. A typical cross section of a wind turbine blade is shown in Figure 2. Depending on the manufacturer of the blade the cross section can contain different materials. However, the main parts like shell and spar and the aerodynamic shape are similar in most blades.



**Figure 2:** Typical cross section of a wind turbine blade. The upper side in the picture is called intake side the lower side is called pressure face. On the left the leading edge (1) and the trailing edge (2) can be seen. The spar (3) stabilizes the turbine blade and is glued to the shell (4). Large areas are built of GFRP (A). To reduce weight some regions (B) are built as composite of GFRP and wood or plastic foam.

Turbine blades are manufactured as semimonocoque construction. The two halves are laminated separately and are glued together afterwards. The material generally is not UV resistant and has to be protected by an opaque gelcoat. As the coating is done before the two halves are linked it is not possible to check the bond between shell and spar by a visual inspection from outside the blade.

The development of non-destructive testing techniques for the use at wind turbine blades would help to make the inspections more reliable. However, the testing equipment should be small and lightweight so that the inspections can be done in service. The techniques should work with a dry coupling or contact free to keep the inspection times short.

## **2.1 Damages in wind turbine blades**

Damages in wind turbine blades are various and various in importance. One can discriminate symptoms of fatigue from manufacturing errors.

### **2.1.1 Symptoms of fatigue**

The turbine blade has to stand great forces and is degraded by the constant wind. During common wind conditions the blade tips reach velocities up to 300 km/h. Therefore the leading edge of the turbine blade often shows erosion due to small particles like dust that hit the turbine blade with very high velocities. If the gelcoat is eroded UV-radiation and water can infiltrate and degrade the GFRP. The trailing edge is highly stressed by the constant stall. Typically delaminations can be observed here. Other damages due to fatigue are for example delaminations within the GFRP-laminates, stress whitening or debonding of matrix and fibers. Erosion of the leading edge is decelerated by protection films that are stucked onto the gelcoat. The load on the trailing edge is reduced using diverse vortex generators to cause an earlier stall.

At the moment several condition monitoring systems for new wind energy plants using embedded sensors are being developed to detect symptoms of fatigue at an early stage. For existing turbines the conventional inspection techniques have to be used.

### **2.1.2 Manufacturing errors**

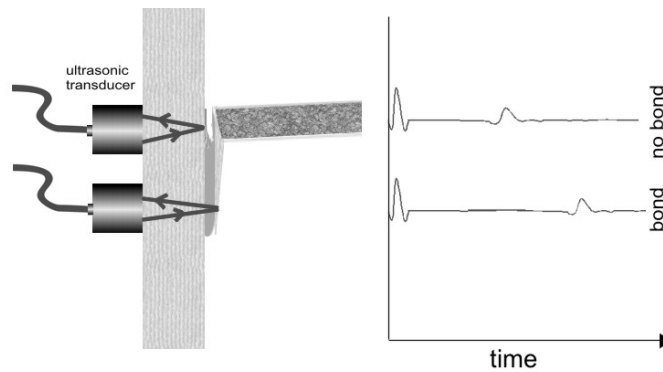
Condition monitoring systems are not able to detect errors that are in the blade from the outset. Although the manufacturing process is widely automated, there are still critical areas which are not accessible with common inspection techniques.

During the lamination process it sometimes happens that the laminates are not immersed with resin evenly or air gets trapped within the GFRP. Sometimes the fiber laminates are not put into the shapes precisely and undulations appear in the GFRP. These areas are mainly not visible during and after the manufacturing process but of course affect the rigidity of the turbine blade.

Critical areas are the bonding areas between shell and spar and between the two halves at the leading and the trailing edge. Due to the gelcoat the bonding process has to be done without a visual control. Some manufacturers use infrared cameras to visualize the reaction heat within the glue during the bonding process [5]. However, this technique is not applied to all operating blades and furthermore is not possible to give evidence about the quality of the bond. Too little adhesive leads to missing bond between the two halves. Too much adhesive brings in additionally weight and can cause unbalanced masses. Furthermore the presence of too much adhesive affects the hardening process and can lead to fissures within the bond. Therefore the inspection of the bond is very important for the sustainability of a turbine blade. An inspection from outside the blade is not yet possible. The access to the inside of a turbine blade is limited to the first third of the blade. Thus an inspection of the bond from inside the blade is also limited.

## **3 Ultrasound-Echo Technique**

The ultrasound-echo technique is a common and very well investigated technique in non-destructive testing [3]. The measurement principle shown in Figure 3 is very simple. The technique is used to detect the bonding areas through several centimeters of GFRP. An ultrasonic pulse is sent into the material. The waves are reflected at material changes or at the back wall. The echo will be very strong and will arrive earlier if there is no bond between shell and spar. If shell and spar are linked very well the clear echo will move to later arrival times or will vanish completely.

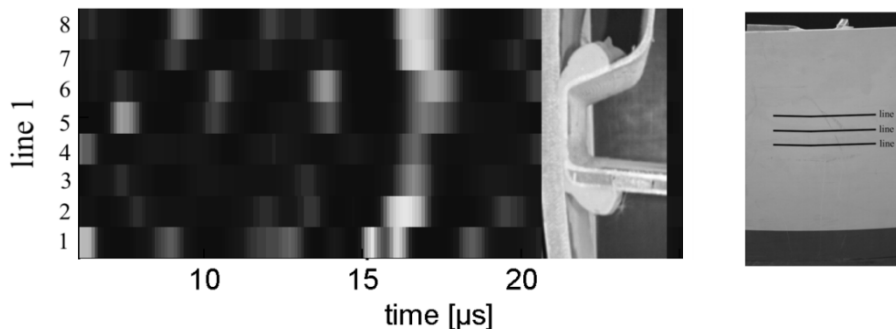


**Figure 3:** *Ultrasound echo at a bonding area of wind turbine blade.*

As GFRP is a highly damping material for sound waves a high voltage pulse is needed. As acoustic and elastic waves are damped each period, high frequency waves are stronger damped than low frequency waves when travelling along a defined distance. Therefore the use of low frequencies is advantageous for highly damping materials. On the other hand acoustic waves are only sensitive for flaws of sizes that lie in the range of the used wavelength. A feasible compromise between damping and resolution had to be found. Broadband ultrasonic transducers with a center frequency of 1 MHz are suitable. A dry coupling of ultrasonic transducers could be achieved by the use of silicon membranes.

### 3.1 Measurements and results

The ultrasound echo technique was applied to a sample of a wind turbine blade containing the bonding area between shell and spar. The sample was about 50 x 50 centimeters big and is shown in Figure 4 on the right. Three lines of measurements were done covering the bonding area.



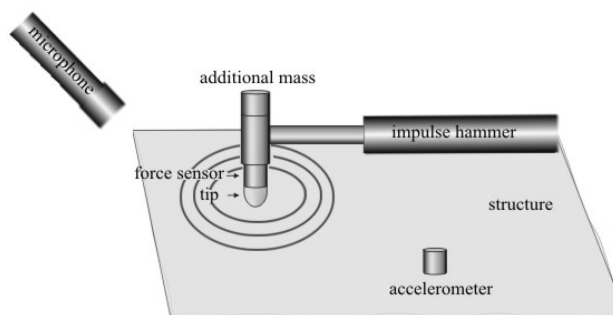
**Figure 4:** *Results of an ultrasound-echo measurement at a wind turbine blade sample.*

The time series of the eight measurements done along line 1 are visualized in Figure 4 on the left. The cross section of the test specimen is also shown in the figure. It can be seen that there's a clear echo at about 16  $\mu$ s in measurements 1, 2, 7 and 8. The echo is getting smaller in the measurements 3 to 6. These four measurements cover the bonding area between shell and spar. The traveling sound waves dissipate in the plastic foam the bars are made from. The absence of the clear back wall echo in comparison of adjacent points allows a statement about the quality of the bond.

## 4 Local resonance spectroscopy

The ultrasound-echo is advantageous for the inspection of thick layers of GFRP. To detect shallow delaminations or air trapped near the surface, the local resonance spectroscopy can be used. The technique is an advancement of the simple tapping tests which are done by the surveyors during the regular inspections of wind turbine blades. The measurement principle is shown in Figure 5.

An impact is generated on the surface of a wind turbine blade using an impulse hammer. The structure starts to vibrate in the region of the excitation and a sound is generated. The excited sound is recorded using a microphone and depends on the contact stiffness of the surface [6]. The contact stiffness is linked to material and condition of the structure. As the contact stiffness also affects the contact time of hammer and material, the force recorded at the hammer tip gives additional information about the inner structure [7].



*Figure 5: Measurement principle of the local resonance spectroscopy.*

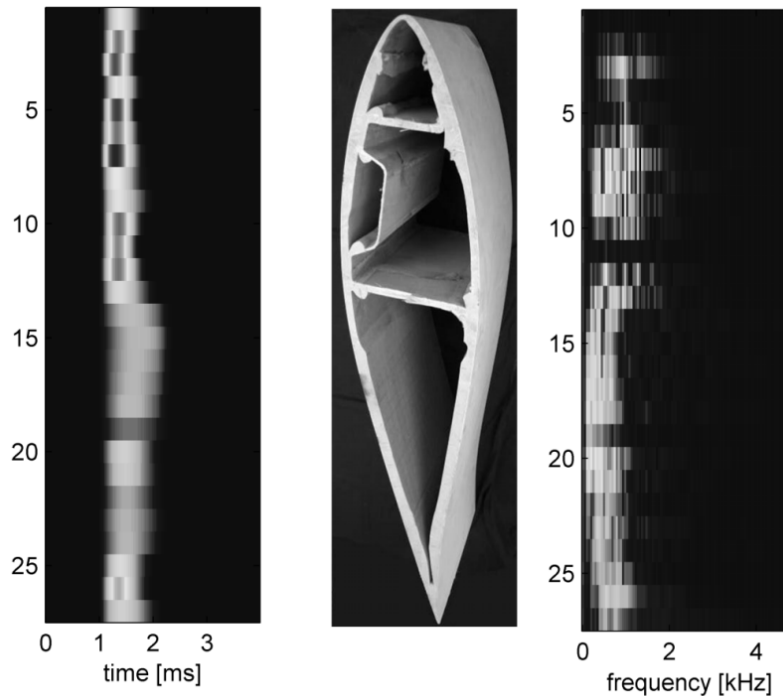
### 4.1 Measurement and results

The described technique was used at an undamaged sample of a wind turbine blade and at a damaged area within a complete turbine blade. The microphone was held approximately 10 cm away from the hammer. The distance is not yet controlled.

On the left of Figure 6 the time series of the excitation force recorded at the hammer tip is shown. Along the cross section of a wind turbine blade 27 measurements were done. Comparing the duration of the hammer signal to the cross section of the turbine blade it can be seen that the contact between hammer and surface is shorter if the impulse is excited to the GFRP areas of the blade.

The contact time is shorter because the material is harder. The sandwich areas are much softer and therefore the contact time is longer.

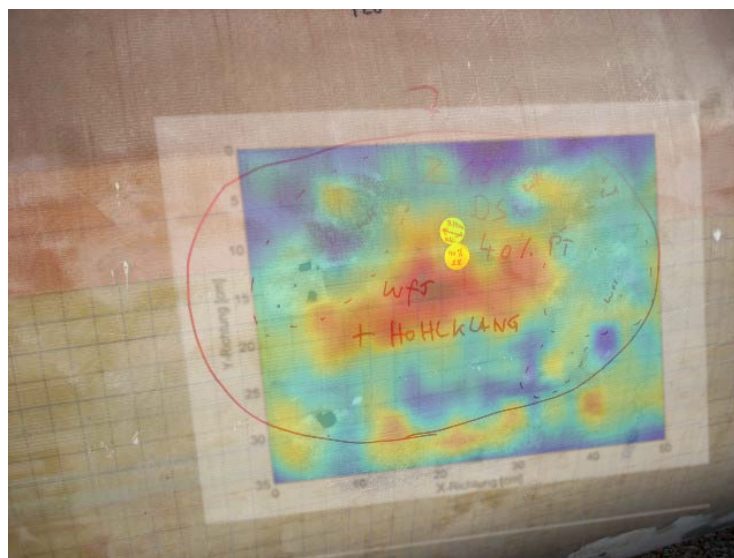
The excited sound of the hammer impulse is recorded using a microphone. The amplitude spectra are shown on the right of Figure 6. As the excitation is shorter the excited sound consists of a broader frequency range. The sound signals of the excitation on the sandwich areas contain only deeper frequencies. Furthermore the measurements 11 and 5 show the smallest sound amplitudes compared to the other measurements. These measurements were done on the bonding areas between shell and spar. The sound is probably damped within the bonding or the sandwich material of the spar.



**Figure 6:** Left: Time series of the excitation force recorded along the cross section of a wind turbine blade. Middle: Cross section of a wind turbine blade. Right: Amplitude spectra of the recorded sound signals.

The excitation signal of the hammer and the excited sound signal give information about the internal structure of a wind turbine blade.

The results of a measurement at a damaged part of an entire wind turbine blade without a coating are shown in Figure 7. The halfwidth of the force signals recorded at the hammer tip are compared to the marks that were done by a surveyor. The darker area in the middle corresponds to a longer contact time between hammer and surface. This area was marked to sound hollow by the surveyor several weeks before the measurements took place. The brighter areas on the right and on the left top correspond very well to areas where air was trapped near the surface. Thus the technique is suitable to detect near surface damages.



**Figure 7:** Halfwidth of the excitation signals at a damaged area of a turbine blade.

## 5 Conclusion and outlook

Due to the increase in renewable energies and especially wind power the safety of wind turbines becomes more important. Two non-destructive testing techniques using ultrasonic and sonic waves were shown in this paper. The ultrasound-echo technique is suitable to detect flaws within the bonding areas beneath several centimeters of GFRP. The technique can be used with a dry coupling of ultrasonic transducers. Therefore no couplant has to be carried up to the turbine blade and in service measurements are possible. In the future a compact equipment that can be carried by an industrial climber would be reasonable and will be developed. It is also possible to link the equipment to an automated system like a robot.

The local resonance spectroscopy is an advancement of the manual tapping tests that are the state of the art at the regular inspections of wind turbine blades. A sound is excited by a hammer impulse on the surface. The excited sound is recorded using a microphone. Additionally the force signal of the excitation is recorded and gives additional information. Using this technique near surface damages can be detected very simple by interpreting the force signals recorded at the hammer. The sound signals can be used to visualize the inner structure of a wind turbine blade. The used equipment for this technique is very small. The sound recording works contact free, so the measurement is very quick and can be automated for the use on a robot.

It has to be marked, that both techniques do not and don't have to work as absolute techniques. A statement of the internal condition of the wind turbine blade is done by a comparison of adjacent points and the knowledge of the principal construction of the blade. It has to be assumed that the exact internal structure of wind turbine blades depends on the manufacturer and will not be known. A comparative technique will be able to find the location of the bonding areas even if it is only known by tenth of centimeters. Both techniques are able to help to make wind energy safer and reduce failures of wind energy plants.

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