199 Anglesea Street
Goderich, Ontario
Canada N7A 1V5
www.composotech.com
Phone: (519) 440-0455
or 1-866-579-9631
Fax: (519) 440-0688

Optimizing Blade Performance to Ensure Post Warranty Turbine Availability

Topic: Operating Wind Project Post Warranty
Prepared For: AWEA – Windpower 2009
Author: Chris Wraith
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Acknowledgements: Jenny Jeffrey
Mike Jeffrey

199 Anglesea Street
Goderich, Ontario
Canada N7A 1V5
www.composotech.com
Phone: (519) 440-0455
or 1-866-579-9631
Fax: (519) 440-0688

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Introduction:

Modern day wind turbines are generally between 1.5MW and 3MW, with designs for 6MW and greater. These turbines typically have blades ranging in length from 30m to 45m and even larger. Blades of this size are normally manufactured within approximately 24 hours and are designed to last 20 years with minimal maintenance, yet most manufacturers only provide a 2 year warranty. Blades are made almost exclusively out of composites consisting primarily of Epoxy Resins (some manufacturers still use Polyester and Vinyl Ester Resins), E-Glass and Foam or Balsa. Due to the speed with which the Wind Turbine Industry is growing and the demand this places on the Original Equipment Manufacturers (OEM's) to design and produce ever larger and more powerful Wind Turbines, there are compromises made during the design and development stages. These compromises lead to shorter design and testing periods in an effort to bring the final product to market sooner.

Composites' used on this scale in manufacturing is a relatively new practice and has required a steep learning curve for the industry. It is integral that for Wind Park Owners and Operators to purchase the highest quality components they available that they ensure "reliability is the key factor, not price – because any rework or repair is likely to remove profitability of a turbine for a long time, if not forever" (Cripps). This means that there is due diligence on the part of the Owner and Operators, not just the OEM's, to ensure the end product quality.

Owners and operators must ensure product quality before the product is purchased and continually monitor product quality throughout its design life. Due diligence begins with an investigation of previous turbine designs and the current manufacturing methods of the potential supplier. From there, the blades will need to be inspected upon arrival and at various stages throughout the operating life of the Wind Turbine. Since most owners and operators do not have the in-house expertise to perform due diligence inspections, typically a third party Independent Service Provider (ISP) is contracted. It is, however, common that post warranty inspections of the wind turbine blades are completed by the OEM companies, as they are the most familiar with the blades.

It is imperative that the wind turbine blade Inspection and Maintenance Program begins as soon as the blades arrive on-site, and continues throughout the life expectancy of the blades. Experience has shown that most problems do not occur until after the blade warranty has expired, however, continuous inspections and preventative maintenance will help to ensure that any damage discovered will most often be minor and less costly to repair. A large scale Blade Remediation Program will be more costly than an effective Inspection and Preventive Maintenance Schedule.

Due Diligence Requirements:

Owners and operators have the responsibility to their investors to ensure that the product they purchase will last through its design expectancy, and that accurate cost estimations are made for the products Operation and Maintenance (O&M). These costs are typically under-estimated and can potentially have a drastic impact on the profitability of the Wind Park as a whole (Burger). Historical trends which show the quality of the final product can be used as a preliminary scale to evaluate potential suppliers, however, more thorough checks must be done.

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A manufacturing and quality audit should be completed to determine if the manufacturer's manufacturing and quality procedures are sufficient to ensure final product quality, and to ensure that they are manufacturing their products in accordance with these procedures. Since most Owners and Operators do not have the in-house expertise to complete this audit, ISP's are typically brought in. ISP's will have the experience and knowledge to provide an unbiased evaluation of the potential supplier. ISP's themselves need to be scrutinized as well to ensure that they have sufficient knowledge and experience to effectively evaluate the potential supplier.

The audit will evaluate every stage of manufacturing, from incoming materials inspection through to final blade inspection, and all stages in between. Evaluation of the product design and manufacturing methods can be accomplished by observing the individual manufacturing stages. Typically, the engineering design is not as thoroughly audited at this stage, as it will have already been approved by an overseeing body, such as Germanischer Lloyd (GL), prior to being scaled for production. Familiarity with the requirements for GL approval is a beneficial, if not a required attribute for those performing the audit. It is important to ensure that the manufacturer follows their quality procedures during full-scale production and that their quality procedures are sufficient to produce a product that will last the full 20 year design life. Based on the findings of the audit, conclusions are then drawn, and provided positive findings are made, purchasing of the components can occur. As well, benchmarks for blade quality will be established.

Maintenance and Inspection Program:

This program will aid in ensuring post warranty availability of the turbine. Using the findings of the audit as the preliminary benchmark for the overall blade quality, inspections and repairs throughout the warranty and continuing into the post warranty turbine operation will help generate a post warranty inspection and maintenance schedule. Ensuring inspections and repairs are completed by teams with blade competence will increase turbine availability, decrease turbine downtime and increase turbine operating efficiency.

On-Site Arrival Inspections:

Once the blades arrive on-site they must be inspected. Exterior inspections of all blades are required to determine if any transportation damage has occurred. OEM's will need to have blade repair crews available on-site to repair any transportation damage, or other damage discovered during these inspections. On-site crews will limit the time required for completing the repairs thereby limiting delays during the site construction, and reducing costs. As well, blade repair crews will ensure that all of the blades are correctly matched in their sets. Incorrectly matched blade sets will lead to avoidable vibrations and decreased turbine performance.

Figure 1 - Transport of Blade Sets

In addition to external inspections, internal inspections on a sample size of blades are required to ensure that these blades were manufactured with the same process and quality procedures as witnessed during the Manufacturing Audit. If any discrepancies are found, these need to be brought to the attention of the OEM immediately, and a more thorough inspection of a larger sample set of blades will be required. Inspections and repairs on the ground are more economical, less time consuming, simpler and safer. These inspections should be done by the same team that completed the Manufacturing Audit, either the in-house capacities of the Owners and Operators or a third party ISP.

All inspections and repairs should be documented with reports and photos. Where applicable, inspection results will then be compared against the benchmarks established during the Manufacturing Audit. These records will need to be kept throughout the entire life of the rotor blade.

Installation Inspections:

Prior to installation of the blades on the rotor, it is important to ensure that the construction company is executing all lifts and installations directly according to the OEM's defined procedures. If done incorrectly, blade damage will likely occur, potentially adding substantial delays and costs to the project. If any damage does occur during these installations, it can usually be easily repaired on the ground or with a man-basket, with limited additional crane costs associated.

At the time of commissioning, two additional inspections should be done:

1. Aerodynamic Alignment
2. Dynamic Balance

Aerodynamic alignment inspections involve inspections for Cone Angle, Partition Angle, Blade Contour and Twist and Angle of Attack. Cone Angle refers to the angle that the blades are located with reference to the turbines tower. Partition Angle refers to the blade angle spacing with respect to each other. Angle of Attack refers to the angle between the blade profile chordline and the rotor plane. Faulty angles will lead to increased vibrations and decreased turbine operating efficiency. Once these measurements are completed, and corrective actions taken if required, the results need to be documented and will serve as benchmarks for future inspections.

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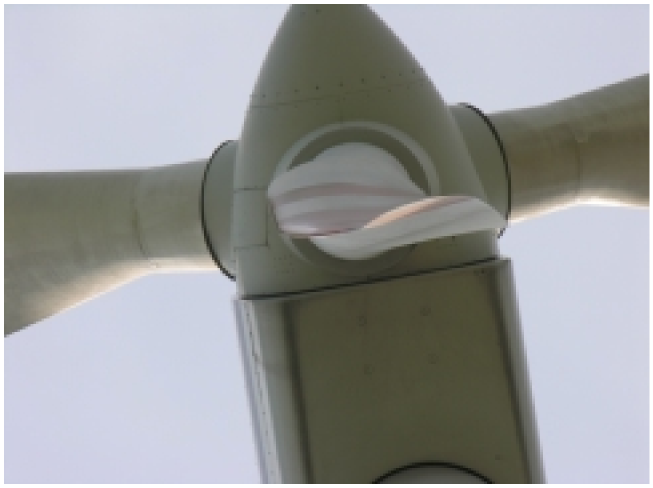

Figure 2 - Aerodynamic Alignment Photograph

Dynamic balancing involves comparing the turbine operating vibration levels with and without a known mass imbalance on the rotor. The results are then used to determine the magnitude of the dynamic mass imbalance of the turbine. In the event of an imbalance, mass is added to the lighter blade(s) as required to balance the rotor. Allowable imbalances will be defined by OEM. These results need to be documented as they will serve as benchmarks for future inspections.

Figure 3 - Dynamic Balancing Set-up

Following these inspections, and repairs as required, the benchmark for turbine operation will be established. This benchmark is then used to evaluate future turbine performance and will serve as a gauge to determine if a certain turbine requires inspections and/or maintenance outside of the standard schedule.

Routine Inspections and Maintenance:

The required frequency for inspections and maintenance of the blades is normally defined within the OEM Maintenance Manual. During the warranty period of the blades, these inspections and subsequent maintenance will be completed by the OEM. It is important that the Owners and Operators ensure that all inspections and maintenance are properly and thoroughly documented with reports and photos. Owners and Operators should review this documentation to become more familiar with the common issues associated with their blades, and to understand the inspection and maintenance procedures employed by the OEM.

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If a large scale blade remediation program is required during the warranty period, it is important that the Owners and Operators insist that a fully designed and tested blade remediation solution is implemented. As any solution will be costly to Owners and Operators, as well as the OEM, it will be tempting to produce an expedited solution; this cannot come at the expense of reliability. Full scale documentation of the repairs completed is also required. Remediation Programs of this scale are becoming more common due to the stresses placed on OEM's to bring their products to market sooner.

Before the blades reach the end of their warranty period Owners and Operators must ensure that thorough inspections and repairs are completed. Either in-house expertise or third party ISP's should be brought in to verify the findings of the OEM. Any additional issues discovered will then be brought to the attention of the OEM, who will either provide reasons for accepting the issues, or provide and implement design solutions.

Once the warranty period has expired, typically 2 years after turbine commissioning, the Owners and Operators have three choices for who will perform the Operations and Maintenance on their blades. These are:

1. Owners and Operators In-house
2. OEM
3. Third Party ISP (Luck)

Since Wind Park Owners and Operators generally have a shortage of In-House Blade knowledge, typically Operations and Maintenance of blades will be done by either OEM's or Third Party ISP's. OEM's are the most familiar with their product and its deficiencies however, they will not be as free to share these deficiencies for fear of degrading the general market perception of their product. Third Party ISP's are generally able to mobilize their workforce faster in the event of emergency repair requirements, however, they lack the detailed product specific knowledge of the OEM, but may have general cross-industry knowledge that can be applied to the products.

Scheduled Inspections and Maintenance should be done at times of low wind to limit the power production losses and if cranes or other blade specific access equipment are required, it is less likely that they will be shutdown due to high winds. There are many companies that can provide reasonably accurate forecasting information if in-house capacities are not available. SCADA data, turbine performance statistics and previous inspection reports should be used to decide which turbines to inspect first and will aid in estimating the time required for performing the inspections and maintenance.

The competence of the teams completing the inspections and maintenance on the blades is as critical a component as price. Performing routine inspections and correctly diagnosing any issues early, will limit the size of the repairs required, and will allow for these repairs to be properly scheduled to maximize turbine availability. Defects discovered may seem insignificant to untrained personnel, however if they are in locations of high stress, they may propagate faster and be signs of larger blade or turbine issues. In these cases, "band-aid" solutions that just mask the problem will not be sufficient. Competent inspection and maintenance teams will understand all these intricacies and develop and implement a sufficient repair procedure. Thorough documentation of the results of the inspections and maintenance must be completed and properly filed.

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Inspection Methods:

There are many methods available to inspect the blades. The primary inspection technique used is visual inspection. In the event defects are discovered, tap testing and shining of concentrated light are simple Non-Destructive Tests that can be employed. Trained inspectors can use these methods to evaluate the general quality of the blade. However, to accurately diagnose the overall quality more advanced inspection techniques may be required. Other standard Non-Destructive Tests are:

1. Thermographic Imaging
2. Ultrasonic Imaging
3. Infrared Imaging (primarily for interior of blade)
4. Continuity check of lightning protection system
5. Shore D and Barcol hardness test of bonding paste and laminate

Depending on the results of these inspections, further probing or investigative grinding may be required to completely understand any defects.

Equipment for on Tower Blade Inspection and Maintenance:

To do preliminary visual inspections of the exterior of the blades, inspectors commonly use field glasses from either the ground or the top of nacelle. The nacelle is generally preferred as the inspector is closer to the high stress areas of the blade, the root and the transition area. Trained inspectors will be able to identify areas of concern while they are still small. The following equipment can be used to investigate the areas of concern while the blades are still on the tower:

1. Man-Basket from Crane
2. Suspended Access Platforms
3. Rope Teams suspended from the Nacelle
4. Truck Mounted High Access Aerial Lift

Provided that the damage is minimal, repairs can be completed at the same time as the inspections.

Figure 4 - Man Basket suspended from Crane

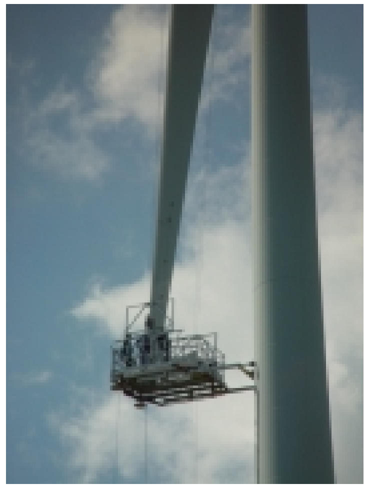

Figure 5 - Suspended Access Platform

In the event of larger damage, or damage to critical areas requiring the blade to be unloaded (no stresses due to static mass) to repair, blades may need to be individually removed from the rotor, referred to as a single blade change-out, or the entire rotor may be dropped. This procedure represents a large cost as high lift and capacity crane(s) are required. Unless it is required as an emergency measure, Owners and Operators should use forecasting to schedule the timing of this repair to minimize crane costs and maximize turbine availability in high wind. If possible, this repair should be scheduled along with the Routine Site Inspections and Maintenance.

Internal inspections should also be included as part of the routine inspections. Inspectors will need to have special certifications to perform these inspections. Confined Space Training and Air Monitoring Equipment are typical requirements for these inspections. Additional safety measures may be required by some companies. These inspections can be done up-tower, however since most turbine designs require inspectors to enter into the hub from the outside, more stringent weather requirements are placed on the inspectors. Wind Gusts not exceeding 15m/s is the standard allowable wind speed most OEM's use as their threshold for entering into the hub. This standard reinforces the requirement of scheduling inspections and maintenance with the aid of forecasting.

Following the inspections, inspectors will need to document all findings and compare them with the benchmarks previously established. If maintenance repairs were required these must also be documented.

Common Blade Defects:

Throughout the life expectancy of the blades, repairs will be required. Many blades operate in harsh environments, exposing the blades to temperature extremes, hot and cold, dirt and dust particles, UV radiation and lightning among others. OEM designs are faced with these factors, which compound any defects or inefficiencies imparted into the final product through the blade design or manufacturing.

Fine dirt and dust particles act similar to sand in a sand blasting operation. With blade tip speeds on some turbines in excess of 70m/s, erosion of the blades Leading Edge (LE) is a common occurrence. If this damage is not repaired blade aerodynamic efficiency will be directly affected. This erosion also exposes the fibreglass laminate to UV radiation, degrading the laminates mechanical properties. Additionally, it simplifies the path for water absorption, also degrading mechanical properties. LE Erosion can be easily monitored through routine visual inspections.

Figure 6 - LE Erosion

Temperature extremes place additional stresses on the blades, and accelerate the fatigue associated deterioration of the blades mechanical properties. These stresses will accelerate the propagation of cracks, as they form.

Ice accumulation on the surface of blades will drastically affect their aerodynamic efficiency and can produce large mass imbalances. Turbines should not be allowed to run with ice on the blades, and typically won’t, due to the large vibrations that form. Blades have buckled due to the additional load imparted by the ice.

Figure 7 - Ice on Blades

Wind Turbine blades are designed to withstand lightning strikes. However due to the extreme temperature change that occurs during this phenomenon, it is not uncommon for blade debonding to occur along the Leading Edge, Trailing Edge and Shear Web(s) or Spar. This can also deteriorate the laminate in the area surrounding the repair. If this defect is noticed, the turbine should be stopped, and a thorough inspection of the laminate, as well as the bond-lines must be done before a repair is completed.

Turbines that operate with large mass imbalances will not operate as efficiently and will expose the individual turbine components to higher than designed vibrations. These vibrations will eventually lead to increased crack occurrence and accelerated propagation. These cracks will act as stress concentrations, and if are unnoticed or unattended to, may lead to complete blade failure.

In addition to these issues, manufacturing methods, typically hand lay-up of dry material (some OEM's do use Automated Tape Laying (ATL) and Automated Fibre Placement (AFP)) into the mold and resin introduction through the process of Vacuum Infusion. Wrinkles and dry spots in the laminate are common defects found when using this process. If these defects are not addressed by the OEM, through their manufacturing and quality processes, they will seriously decrease the life expectancy of the blade, and may result in a full scale Blade Remediation Project being required further down the road. Other defects such as incorrect placement of blade support structures (Shear Webs, Bonding Flanges and Spar Caps), insufficient bonding paste and improper surface preparation will also lead to decreased blade life expectancy. Issues such as these will typically be identified during the Manufacturing Audit, if they exist.

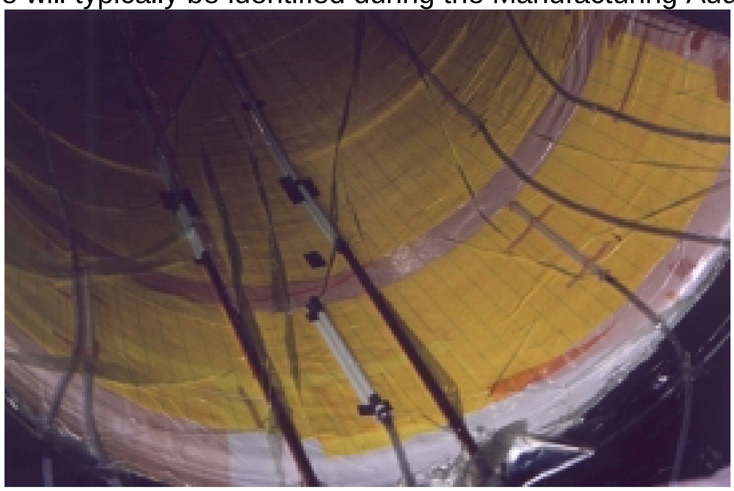

Figure 8 - Infusion Lay-Up

Performing Repairs:

Repairs, depending on their severity, as well as the ambient environment conditions, will occur in one of three locations:

1. On-Turbine
2. On-Site on the Ground
3. Off-Site Repair Facility

On-turbine repairs are generally the most cost-effective solution, especially when scheduled as part of the site wide inspections and maintenance. However, this solution is generally limited to minor repairs. On-site on the ground repairs are simpler and safer to complete and can be more extensive, however, they are still subject to many of the same environmental concerns as on-turbine repairs. Some of these concerns can be offset by constructing temporary tents. Large and very extensive repairs must be done at an Off-Site Repair Facility. Depending on the frequency of the required repair, such as a product wide refurbishment program, the required scale of the repairs may dictate that a central repair facility will be more economical then sending satellite teams to individual sites.

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Figure 9 - Off-Site Repair

If blades must be removed from the rotor to complete the repairs, it is recommended that both Aerodynamic Alignment and Dynamic Balancing of the rotor be completed. This alignment and balancing will decrease the overall vibrations of the turbine, increasing the lifespan of the turbine's individual components, and operating efficiency. Repairs completed with the blades still on the rotor may also require that the rotor be Dynamically Balanced. Minor repairs at the tip, due to the size of the blades can result in a large mass imbalance.

If following the inspection, required repairs are not completed, dire consequences may occur. This may also occur if the Owners and Operators feel that an Inspection and Maintenance Program is not required, or not correctly implemented. Experience has proven that absent or ineffective inspection and maintenance programs will severely decrease the operating life expectancy, power performance and availability of the Wind Turbine. Catastrophic Rotor Blade and/or Turbine failures have been known to occur.

Figure 10 - Catastrophic Turbine Failure

Conclusions:

Wind Turbine blades are designed to have an operating life expectancy of 20 years, however most manufacturers only provide a 2 year warranty. An effective blade inspection and maintenance program is required to ensure that the blades reach this expectancy. This program must begin at the initial manufacturing of the blades and continue throughout the entire blade life expectancy, ensuring that any defects found in the blades are noticed early and correctly repaired. Blade competence is a requirement for completing both the inspections and the repairs. Typically, Wind Park Owners and Operators do not have this competence available in-house. This knowledge is a requirement for maximizing post warranty turbine availability. Owners and Operators must then outsource the blade inspection and maintenance work, to either the OEM or third party ISP's. Establishment of operating benchmarks early in both the blade and turbines life will aid for future comparison and evaluations of the blades' overall quality. Complete documentation of all inspections and repairs through the warranty period will help to establish a post warranty inspection and maintenance schedule.

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