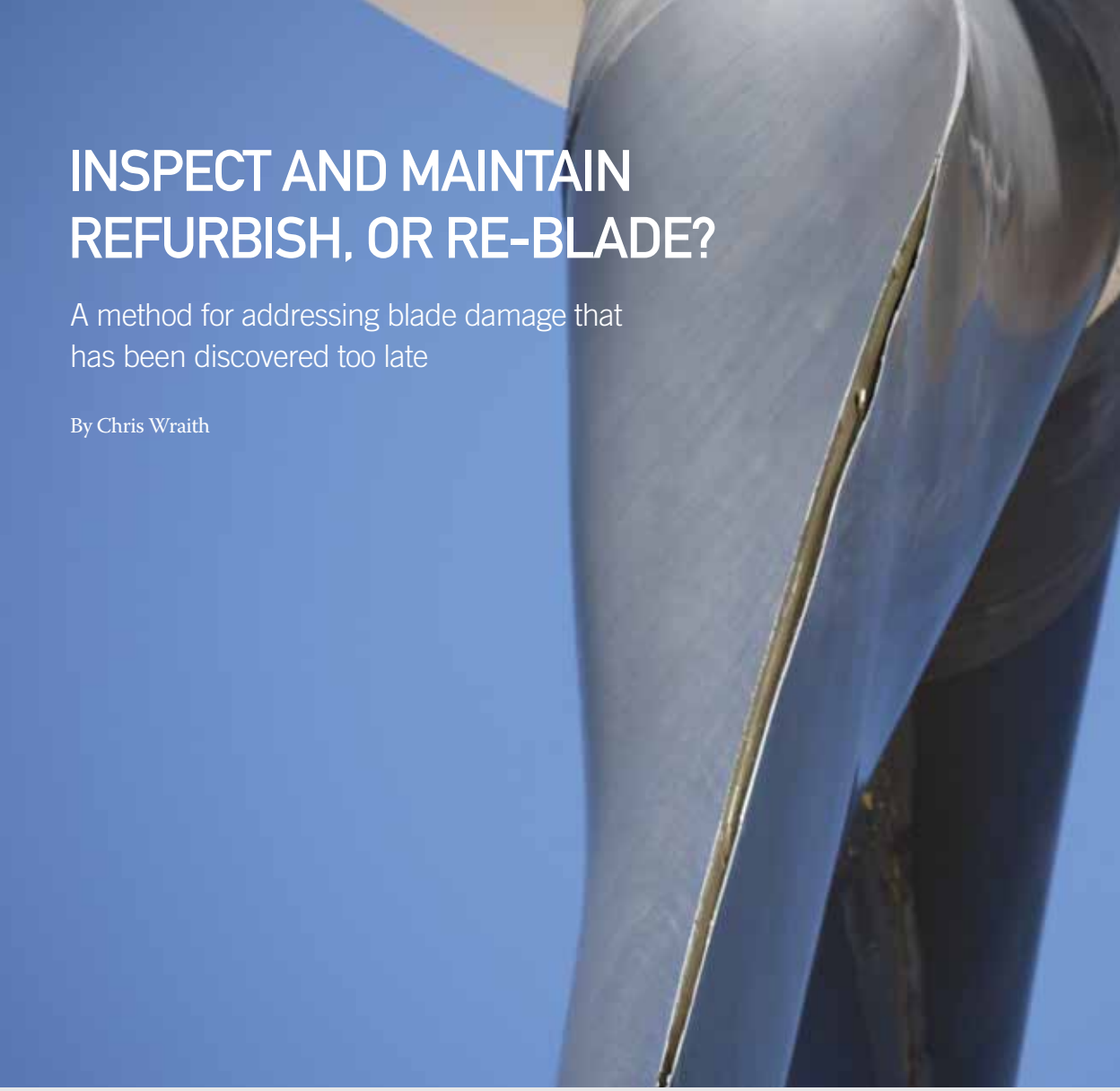
INSPECT AND MAINTAIN REFURBISH, OR RE-BLADE?

A method for addressing blade damage that has been discovered too late

By Chris Wraith



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AS TODAY'S OPERATING WIND TURBINE ASSETS age, owners and operators are being straddled with higher operation and maintenance costs than those experienced during the early years of operations; in many cases, more than those assumed within the pro forma. These cost increases are particularly common for wind turbine rotor blades. Even many of those operators who have signed long-term maintenance and service contracts will discover they aren't immune to these rising costs.

Most owners and operators do not perform full-scale rotor blade inspections on the operating fleet after end-of-warranty, and are typically only carried out after the field technicians start to report increased signs of damage or when higher associated rotor blade maintenance costs dictate that the inspections be performed to get a better understanding of the conditions of the rotor blades on-site. Once the rotor blades reach this condition, on-site/on-tower repair becomes much more costly and impractical, and other options must be considered. These are commonly:

A. Allow the turbines to operate with minimal maintenance and plan for near-term re-powering of the site

B. Re-blading the wind turbines with newer blades of the same or greater length
C. Refurbishment of rotor blades
D. Some hybrid solution of b and c

Most owner/operators do not have the in-house rotor blade knowledge required to perform the comprehensive assessment of their rotor blades in order to understand their current operating condition. For this reason, many third party independent service providers (ISP's) are brought in to perform these inspections and aid in the decision-making process for addressing issues with the rotor blades. Provided that the condition of the rotor blades is not so deteriorated that options "A" or "B" are the only feasible solutions and on-site repair is no longer an economical option, most companies prefer option "D".

Option "D" is generally used due to the ramp-up time associated with the refurbishment process, as most spare rotor blade sets are not normally readily available on-site. At minimum, a lag-time of 4–6 weeks can be expected from the time the rotor blades are removed from the turbine until the refurbishment is completed and the blades are ready to be re-installed. Subsequent rotor blade sets can be expected to be available at much lower lag-times. In order to minimize this downtime cost, new rotor blade sets are purchased, when possible; when not possible, older rotor blades that can be matched into a set are sought and purchased. As is most often the case, these older rotor blades require some degree of refurbishment before being installed, so in many instances these rotor blades are the first to go through the refurbishment process.

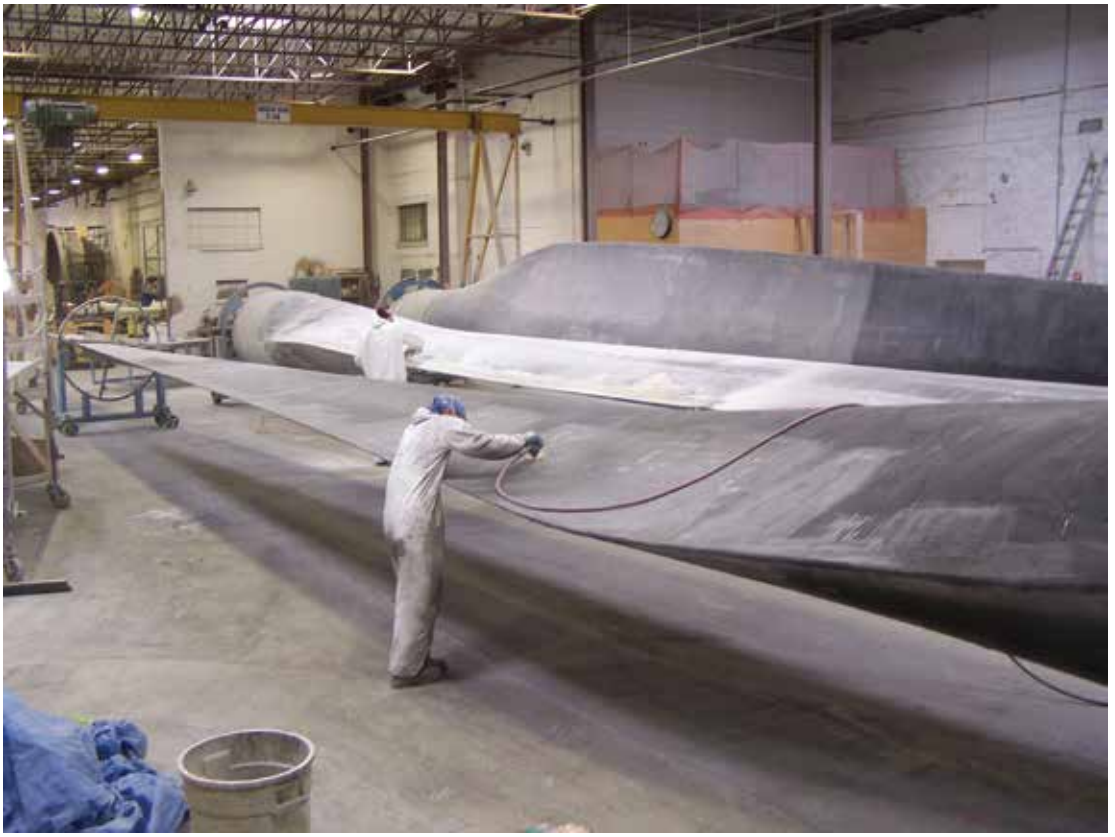
What is involved in the refurbishment process?

From the inspection findings, a detailed understanding of the wind farm rotor blades condition is known. When the discovered damage includes defects such as extensive surface coat cracking; flaking; erosion; chord-wise and span-wise cracking in the max chord and transition area; leading edge (LE) erosion; and interior defects affecting a high percentage of the rotor blade population; an off-site refurbishment plan is usually found to be the most cost effective solution—if repair is even economically feasible. In order for an owner and/or operator to proceed with this process, a number of steps need to be taken and items considered:

STEP 1: PROJECT TENDER

If the work is to be performed by third party contractors, the work should be tendered to multiple potential contractors. Within the tender, a detailed scope of the work to be performed provided with the request that a fixed price for refurbishment be provided. For this reason, most owners and operators work diligently—with outside consultants when required—to establish which of the common defects require repair; and ensure that these defects are repaired under the standard scope of repair. Time and materials rates are also requested for defects requiring repair that are out of the original scope of refurbishment definition.

Establishing, before submitting the request for tender, which rotor blade repairs need to be included as part of the fixed set refurbishment cost is critical to obtaining a higher level of



cost certainty for the project. However, careful consideration must be given to which repairs are and are not critical, as this can greatly influence the overall set refurbishment cost. When replacement rotor blades are available, refurbishment costs above 40–60 percent of new rotor blades costs are generally considered as the upper limit. At a minimum, the following classes of defects require repair:

1. Interior and exterior structural defects that will have an effect on the safe operation of the rotor blade during the expected operating life
2. Lack of continuity in lightning protection system down conductor
3. Blocked drain holes
4. Missing and damaged aerodynamic elements

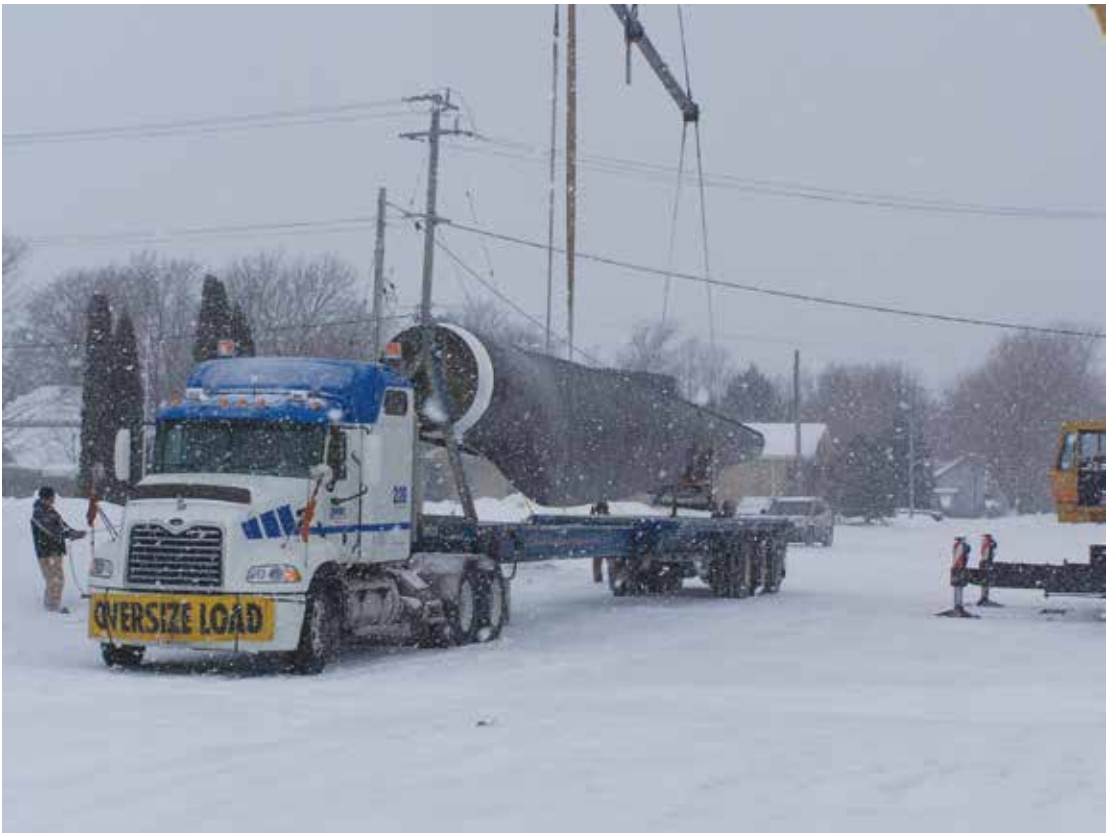
Additional repairs will influence the overall set refurbishment cost. However, careful consideration must also be given to the following:

1. The condition of the LE of the rotor blade commonly deteriorates. Based on an assessment of the current condition at the time of refurbishment and the local site conditions, the application of a supplementary LE protective coating is typically performed.

2. A number of interior and exterior structural defects will be discovered during inspection following operation of the rotor blades. Not all of these defects will have an effect on the safe and continued operation of the rotor blades within the rotor blade design life. Taking a conservative approach when selecting which defects require repair will increase the refurbishment cost, but will likely decrease the long-term operating costs.
3. Re-application of the final surface coat following completion of repairs is recommended for three main reasons:

a. A very patchwork surface results from the refurbishment process. This will leave the final surface condition of the rotor blade very unaesthetic.
b. Wear of the surface coating will occur as the rotor blades continue to operate. Re-coating will ensure areas of thin coating are repaired.
c. A refurbished surface coating will facilitate defect discovery during subsequent rotor blade inspections.

If, as is commonly requested, the contractors request access to a sample of the rotor blade population prior to responding to the request for tender, this access should be granted. It can be expected that through this inspection, the individual



contractors will gain a better understanding of the rotor blade condition, and be able to provide more accurate pricing.

It is also important that, as a requirement of responding to the tender, the contractor is able to provide demonstrated knowledge of the specific rotor blade materials and design as well as the general practices within the rotor blade repair industry. If this information cannot be provided, the contractor must be able to describe the processes that will be employed to determine this information and ensure the integrity and continued safe operating ability of the refurbished rotor blades.

STEP 2: SELECTION OF CONTRACTOR

Selection of the contractor to perform the work cannot be awarded solely on a lowest-tendered-quote basis. Careful consideration must be given during this process and individual site visits to assess the individual contractor's capacity to perform the required work should be performed.

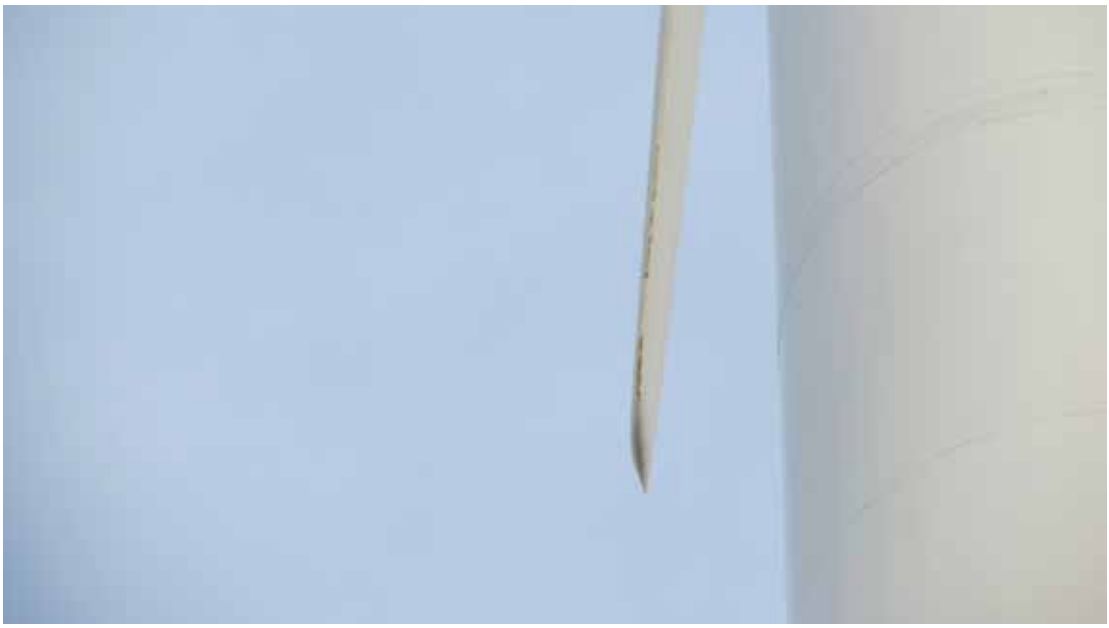
Depending on the scale of the wind farm, the number of years planned for refurbishment and the capacity of the individual contractors responding the request for tender, multiple contractors may be required to complete the refurbishment project.

STEP 3: DEVELOPMENT OF STANDARD REPAIR PROCEDURES

If possible, the development of standard repair procedures should be performed prior to commencing with the rotor blade refurbishment process. Individual procedures for all of the common defects specified within the request for tender are required. This is an arduous task, and the required development of 10–20 procedures or more, is not uncommon for the full scale refurbishment process. However, as this generally set-up as a milestone event in the process, the contractor has the required encouragement to perform and complete this task.

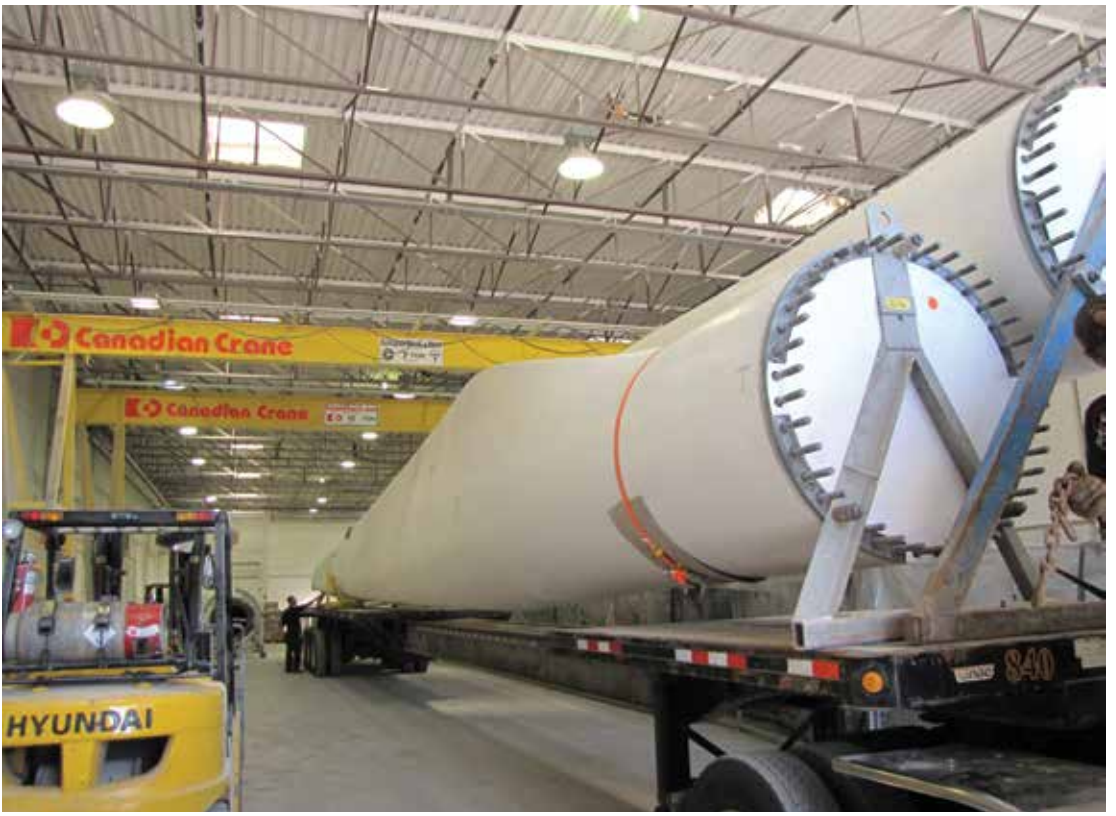
Accordingly, standard repair procedures contain at least the following information:

1. Specific defect condition for which the standard repair procedure applies
2. Acceptance limits for the individual defects before repair is required
3. Materials to be utilized
4. Allowable ambient environmental conditions
5. Specific and detailed instructions for performing the repair
6. Reference to quality control check and hold points



STEP 4: QUALITY ASSURANCE

A quality system designed to ensure that all inspections, repairs, and documentation are being performed as per project expectations; and where available, defined policy, is required before beginning with the refurbishment project. Once the quality system is implemented, it must be clear that at every stage of the refurbishment process a quality control plan is present and being followed. Insufficient quality control will lead to variability in the refurbished rotor blades end quality, potentially leading to increased operating costs.



Periodic audits of this system should be considered as an integral part of the project due diligence.

STEP 5: PERFORMANCE OF STANDARD AND OUT OF SCOPE REPAIRS

All defects that have a standard repair procedure must be repaired following the prescribed procedure. This ensures repair and refurbished rotor blade final condition consistency. Any and all defects that are to be repaired according to a specific standard repair procedure that are not repaired as per the standard repair procedure should be recorded as a non-conformance.

Out-of-scope repairs are for defects that require repair without a standard repair procedure. The sub-process for developing, approving, and performance of out of scope repairs must be decided prior to commencing with repair portion of the refurbishment process. As these repairs represent a cost increase to the fixed rotor blade set refurbishment cost, the scope of the repair must be clearly defined so that cost and quality assurance can be tracked and maintained.

STEP 6: DOCUMENTATION

As part of the delivery package for each rotor blade set, the following documentation, at minimum, should be requested and provided:

1. Interior and exterior inspection findings and defect disposition
2. Repairs performed and procedures used
3. Rotor Blade Set Balancing
   a. Individual Rotor Blade Mass
      1. Inclusive of mass added and location added at to balance
   b. Centre of Gravity
   c. Individual Rotor Blade Static Moment

STEP 7: ROTOR BLADE SET MATCHING

Following the refurbishment of the rotor blades, the deviation between the individual rotor blade static moments is almost always above the allowable limit, necessitating the need for mass addition to balance the rotor blade set. Establishment of what this acceptance limit is should be performed prior to commencing with the refurbishment process. In all instances, if an OEM specified imbalance limit is available, it should be utilized. In the event no OEM specified limit is available, technical rationale for the acceptance limit to be utilized is required.

As part of the original rotor blade design, sealed compartment(s), which are accessible from the exterior of the blade, are bonded in the rotor blade to allow for the addition of mass in order to match the individual static moments within the rotor blade set. Unfortunately, the records for the mass added to

these compartments during original manufacture are not commonly available. Additionally, in many cases these compartment(s) have already been filled to max capacity. For this reason, as part of the refurbishment process, if not already defined, limits must be established for the allowable mass quantity addition and location(s) for balancing rotor blade sets. Uncontrolled mass addition to the rotor blade may lead to the development of non-design operating characteristics, affecting the safe operating condition of the turbine.

Although the rotor blades to be refurbished began as matched rotor blade sets, following refurbishment, all of these blades will not be able to be placed in their original matched sets, due to the mass addition limits defined above. For this reason, a minimum work in progress (WIP) of approximately 3 sets is recommended. With the increased number of blades in WIP, and the common practice of some wind turbine OEM's to have rotor blades manufactured from different rotor blade OEM's at the same wind farm, owners and operators must be diligent in ensuring that only like operating characteristic and aerodynamic profile rotor blades are matched and whenever possible, that rotor blades are matched in sets by manufacturer and mold.

STEP 8: RE-INSTALLATION ON TURBINE

Incoming inspection of the rotor blades prior to re-installation on the rotor hub is a due diligence check that is required. Transportation damage is commonly found, and should be repaired at this time, as the ease of access to the rotor blades and repair will provide long-term cost savings.

Additional due diligence checks such as testing of rotor mass imbalance and aerodynamic imbalance should be considered. Failing to perform these due diligence checks may lead to greater than design loading in the rotor blades and through the wind turbine drive train and structure.

STEP 9: DEVELOPMENT OF COMPREHENSIVE AND THOROUGH LONG TERM MAINTENANCE PLAN

Through the refurbishment process substantial costs will be incurred. In most cases, these costs could have been minimized through the development of a thorough and comprehensive long term maintenance and inspection program implemented during the original project commissioning. To avoid Einstein's definition of insanity and repeating the original process and expecting a different end result, it is imperative that a program be developed. If an in-house model is not already available, owners and operators are encouraged to work with the contractor(s) performing the refurbishment and other industry experts to develop a cost effective program that remains sufficiently comprehensive.