Manufacturing of turbines (gas, steam, hydro and wind)

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Week - 08

Lecture 39

Welcome to this course on manufacturing of turbines. In this lesson 39 of the course, we will see the topics of damage prevention, repair and quality assurance and testing for the wind turbine blades. So, the outline of this lesson will include the introduction to wind turbine damage, types of damage in wind turbines, damage assessment, damage assessment techniques, damage prevention strategies, various repair techniques for wind turbines and quality assurance. As we have seen the wind turbine or the wind turbine structures, they are made up of different materials. Primarily the blade of the wind turbine, they are typically made from the fiber reinforced composites. Example the glass fiber reinforced plastics or carbon fiber reinforced composites.

These are made with these materials with the objective to design for high strength to weight ratio and good fatigue resistance. Whereas, the tower and the nacelle of the wind turbine, it is basically made up of steel and the towers are generally made up of concrete. The nacelle as we know it houses various critical components of the wind turbine which include the generator, gearbox and control electronics. So, here we see that the different parts of the wind turbine blade which include the blades as we have seen, nacelle is behind the blade.

We have the hub on which the blades are connected. The rotor nacelle assembly is sometimes also known as RNA and the whole thing is mounted on a support structure which consists of a tower. Then, there is a substructure that is below the main sea level and then there is a monopile which is below the mud line. So, these various components of the wind turbine as we have seen they experience different sort of conditions because of which there may be different type of damages. So, the common damage mechanisms in the wind turbine they include the operational stress which is the repeated loading and unloading due to wind gusts leading to damage due to fatigue.

The second type of factors include the environmental factors in which erosion from airborne particles, ultraviolet radiation, temperature fluctuations and moisture ingress may occur. So, here we can see that the modern wind turbine blades because are made up of the different types of materials which are combined together, and primarily it is the fiber reinforced plastics or composites made up of glass fiber or carbon fiber being used on the shell of the blade. In the inside of the blade, the cut section, we can see these are adhesively bonded to a core material and this core material provides the strength to the hollow blade. And in the glass fiber also, the composite materials are lined up as laminates, stacked up as laminates, on top of which there is a gel coat provided to prevent the ingress of moisture from the rain or the surroundings. So, if we look at the different types of damages in the wind turbine, so here we start with the high impact damage.

So, these type of damages, they lead to severe structural damage because these damage can lead to compromise with the structural integrity of the wind turbine, it is very important to assess these type of damages. So, these type of damages may essentially be caused because of lightning strikes bird or debris strikes, fatigue induced cracks. So, if we look at the lightning strikes, so these can be caused because of bad weather or stormy weather. And lightning strikes are very common on wind turbines because they are having very high structures on which the lightning can easily strike. So, these lightning strikes can cause delamination burn marks or puncture in the blades.

So, this can also lead to impact on the electrical systems of the wind turbine which are housed in the nacelle, thereby necessitating the immediate repair of these components. The bird and debris strikes, they can lead to localized fractures, material loss and potential aerodynamic inefficiencies. Fatigue induced cracks, so this can result from cyclic loading over time leading to crack initiation and propagation in composite materials. The detection often requires use of advanced non-destructive testing methods due to potential of being a hidden damage. Next, type of damage on the wind turbine blade are the low impact and collateral damage.

So, in this regard the micro cracking and erosion are the two types of damages. The micro cracks can develop due to minor impacts or thermal cycling leading to potential moisture ingress and eventual delamination. This often requires use of ultrasonic testing for detection. Erosion is basically caused on the leading edge of the wind turbine blades and it is a critical issue in the wind turbine operation as leading edge erosion is caused by several environmental factors which include rain, dust and other airborne particles. The effect of erosion is that it reduces aerodynamic efficiency and can lead to further damage if left untreated.

Next, is the topic of the damage assessment. Once, the damage has occurred on the wind turbine or wind turbine blades, it is very important to assess the exact location of damage, the extent of damage. So, the purpose of damage assessment is basically to ensure the structural integrity, preventing catastrophic failures and extending the lifespan of turbine components, particularly blades and nacelles. Non-destructive testing techniques are critical in detecting internal and external defects in wind turbine components without causing further damage. So, the application areas where the damage assessments need to be commonly done include the blades of the wind turbine.

As we have seen the blades are made up of polymer composite materials which are prone to delamination, micro cracking and erosion damage. Next, is the nacelle, as we have seen the nacelle of the wind turbine houses critical machinery such as gearbox, generator, where early detection of cracks or damage is vital. Third is the tower of the wind turbine on which the whole blades and the nacelle is mounted. Towers can experience fatigue, crack and corrosion which can develop over time. Thus, it necessitates the regular inspection of the tower for any type of damage.

So, now we can see the different types of damages that can occur on the wind turbines. So, this includes abrasion, cracking, cutting, delamination, denting, gouging, hole and scratching. So, abrasion is basically the phenomena in which a portion of the surface is borne away by nature or mechanical or manmade means and this may lead to penetrate only on the surface finish. So, in the cross section of the abrasion, we can see that it is only the surface or slightly the subsurface of the part or the wind turbine is damaged. Next, is the cracking in which fracture of the matrix or fiber can occur and this can be more deeper compared to the abrasion type of damage.

In the cut damage, the fibers may be severed by a sharp edge and this can also be deeper than the abrasion type of damage. Delamination is another popular type of damage which can occur in wind turbine especially on the blades. Moisture ingress because of previously occurred damages may lead to opening up of the various layers in the laminates, thus causing delamination. So, this leads to separation of adjacent plies. Next type of damage is dent.

So, dent is basically a concave depression that does not rapture the piles around or debond them in the composite structure. Gouge is the next type of damage that can occur on wind turbine components and this is a special type of dent where, some but not all composite plies may get severed. Next, is the formation of hole where penetration through the outer composite laminate which can lead to damage on the core material in the structure. Scratch is basically an elongated surface discontinuity due to damage that is very small in width compared to its length. Other than this, there may be some other types of damage which can occur.

This can include skin and or adhesive debonding or it can also include adhesive joint failure. Because the outer shell of the wind turbine blade made up of the fiber reinforced plastics is adhesively bonded to the core and adhesive joint failure can occur. Then, there can be adhesive joint failure at the leading edge where the two halves of the blade are joined. Splitting of fibers may also occur, delamination as we have seen can also occur or there can be generation of channel cracks or gel coat cracks on the top surface of the wind turbine blade through which again the moisture ingress can take place. So, if we see the wind turbine blade in case of the performance analysis, so the fatigue strength of the wind turbine blade is the key design requirement.

As we have seen, the size of the wind turbine blades is increasing with every passing year. Therefore, the tendency of fatigue failure is also increasing. So, here we can see the comparison of number of fatigue cycles to failure for different types of structures or other structures where fatigue loads are there and we can see here the wind turbine blades are designed to handle the largest number of fatigue cycles to failure to have an overall service lifespan of 20 to 30 years. So, in this regard we can also see the arrow shell and the webs which are provided in the wind turbine blade to prevent buckling. Here, we can see the adhesive joint which is there which is joining the two halves of the wind turbine blade both at the leading edge that is here and at the trailing edge that is at the back.

So, other than this there can be load carrying laminates which can be in tension or tension compression, tension-tension, compression-compression and there is also a sandwich between these layers and these webs which are providing the core to the wind turbine blade thereby enhancing the strength of the wind turbine blade. So, we can see there are several regions or several specific points which, can cause failure of the overall wind turbine blade and because of which there needs to be proper care taken for the damage assessment because of any types of reason as discussed previously. Next, are basically the damage assessment techniques. These techniques primarily rely on non-destructive testing methods to assess the location and the extent of damage. Among several non-destructive testing techniques, some of the techniques are quite popular.

So, in this regard, the first technique is the ultrasonic testing. So, ultrasonic testing is based on the principle of high frequency sound waves that can be transmitted into the material and the reflection or echoes of this from the defects can be analyzed to identify internal flaws in the structure. The different techniques in the ultrasonic testing include pulse echo and through transmission. The pulse echo technique is suitable for detecting shallow defects near the surface such as delaminations or voids in composite materials. The through transmission involves transmission of ultrasonic waves from one side and receiving them on the opposite side.

Any reduction in the signal strength can indicate a possible defect in the structure. The blades of the wind turbine are largely inspected using ultrasonic testing which can identify delamination, voids, internal cracks particularly in load bearing regions of the blade. So, here we can see the schematic where the spar inspection on the top and spar inspection is conducted using ultrasonic C scans. And another important advantage with ultrasonic testing is the portability of the ultrasonic testing equipment, which can be also being used on field. The next technique in the damage assessment is the thermography.

So, the thermography technique relies on use of infrared cameras to detect variations in heat flow within the material. Defects such as delaminations or moisture ingress can disrupt normal heat flow, making them visible as hot or cold spots. In the thermography also there are further two techniques which are used to do the damage assessment in wind turbines. These include active thermography and passive thermography. Active thermography involves heating the material and observing the heat diffusion to identify the defects.

The passive thermography utilizes naturally occurring temperature differences, for example, because of sunlight to detect the defects. So, thermography is widely used to detect plate surfaces as effective as these are effective for detecting subsurface defects and moisture ingress that can lead to further degradation in the wind turbine blades. Next, technique is basically the use of X-ray and computed tomography or sometimes it is abbreviated as X-ray micro CT. So, X-ray computed tomography relies on the principle of the ability of the X-rays to pass through the material and the difference in the density or the internal structure captured to reveal the defects. The various techniques under the X-ray and computed tomography used are digital radiography and computed tomography.

Digital radiography involves use of two-dimensional images to detect cracks, voids and foreign inclusions within the material. On the other hand, the computer tomography offers a three-dimensional imaging with a detailed view of internal structures, making it ideal for complex geometries and densely packed composite layers. The application includes the use of X-ray and computed tomography on the nacelle and hub inspection of the wind turbines. As detection of cracks and voids in thick composite and metallic components is possible using x-ray as the tool for detecting the damage. Next, is the use of fiber optic sensors to do the damage assessment on wind turbines.

So, fiber optic sensors rely on embedded optic cables which change in which senses the change in strain temperature or vibration within the structure. So, here techniques involve use of Bragg grating sensors which measure strain by detecting shifts in the wavelength and light reflected from specific points along the fiber. Applications of this technique involve real-time blade monitoring which can provide a continuous data of blade stresses, deformation, allowing for predictive maintenance. So, we can say by use of optic sensors, we can develop smart blades which can provide the continuous data and the continuous assessment of the health of the blade can be done. Next, is the damage prevention strategies.

So, in the damage prevention strategy, the material selection and design consideration play a very important role. So, here use of toughened epoxies and thermoplastics are very vital. Selection of toughened resins can improve impact resistance and reduce crack propagation. So, here use of thermoplastics versus thermosets. So, thermoplastics are known to offer better impact resistance, easy repair ability but are quite challenging to process compared to thermosets because of their inherent high viscosity which has poor wettability with the fiber.

Second, are the reinforcement strategies. As we know in composite material, the reinforcement plays a very important role. So, use of aramid fibers are known for superior impact resistance or often combined with carbon fibers to enhance the impact resistance of the composite. Then, is the use of three-dimensionally stitched or woven reinforcement which can enhance the through thickness strength reducing the likelihood of delamination. Next, are the repair techniques for the wind turbines.

As we know the wind turbine blades are quite expensive to not only manufacture but, it is logistically very challenging and cost intensive to install these wind turbine blades. So, in case there is the damage is assessed so very often it is pragmatic to repair the wind turbine blade rather than replace it. So, there are several challenges in blade repair on the wind turbine. So, these challenges include the critical factors that wind turbine repairs must restore the original strength, stiffness and aerodynamic properties of the component. Repairs must be able to withstand the harsh environmental conditions which include temperature fluctuations, ultraviolet exposure and moisture.

So, here the use of external doublers are done where, they are conceptualized on the use of doublers as additional layers of material bonded or bolted over the damaged area to restore structural integrity. The process of installing external doublers involve material selection where pre-cured composite laminates are typically used for their high strength to weight ratio. The application of doublers are applied over the damaged area and are often used with close tolerance bolts or structural adhesives to ensure a strong bond. External doublers have advantages of simply being applied and effective for thick laminate repairs where added thickness is not a concern. There are challenges in installing of external doublers which include the potential of increased weight and altered aerodynamic properties which require careful considerations in blade repair.

So, here we can see the schematic where the use of external doubler and single scarf repairs are conducted on composite laminate and sandwich laminate. So, we can see the single scarf is generally not increasing the thickness whereas the external doubler is increasing the thickness. So, there has to be a careful consideration of the optimal choice of the repair technique. Second is the use of flush type bonded repairs. So, flush type bonded repairs are conceptualized on removing damaged material and replacing it with new laminates, that are bonded flushed with the original surface.

So, various steps in installing flushed type bonded repairs include damage removal where, damaged material is first carefully removed using a diamond coated tool to avoid further delamination. Next, is Scarfing where the damaged area is tapered or scarfed at a ratio of 40 is to 1 to 60 is to 1 to create a large bonding area ensuring gradual load transfer and minimizing stress concentration. Next, is ply by ply reconstruction where, new laminates are applied one by one matching the fiber orientation and material properties of the original structure. Then, is use of vacuum bagging where the repair bay area is vacuum bagged to remove air and ensure high quality bond between the layers. The fifth step is the curing step where repair is cured and using controlled heat and often with a portable curing system that replicates the original manufacturing conditions.

So, here we can see the installation of flushed type of the bonded repair where there is no increase in the overall thickness or weight. So, this advantage advantages of flush type bonded repair provides a original surface maintaining aerodynamic efficiency and structural integrity. So, the challenges in applying the flush type bonded repair is the use of skilled technician and precise material matching to ensure that the repair meets the original design specifications. Next, is use of adhesive bonding where the structural adhesives such as high strength epoxies are used to bond repair the material to original structure. Steps involve surface preparation which is critical to bond for durability.

Surfaces must be meticulously cleaned, dried and free of contaminants. Adhesive application involves a thin application of a thin layer of adhesive that is bonded to the repair material and prepared surface to ensure full coverage. Curing involves the bonded area being cured under controlled conditions to achieve maximum bond strength, often involving post-curing at elevated temperatures. The advantages of adhesive bonding involve a strong durable bond capable of withstanding operational stresses and environmental exposure. Challenges of adhesive bonding involve adhesive of being sensitive to contamination and they must be carefully managed for long-term degradation.

So, here we can see a portable heat system being utilized to repair the composite part and this type of portable system is similar to the vacuum bagging system that we have seen earlier for manufacturing. But, as it can be taken to the damage site, so portability offers a more versatile application of such system in repair techniques for wind turbines. Next, is the repair verification and quality control. So, it is very important to ensure that whatever repairs are done, they are of the requisite quality and there is the proper documentation of such repair steps. Post repair entity are conducted where use of non-destructive testing methods such as use of ultrasonic testing or thermography are employed to verify the integrity of repair.

Inspection criteria ensures the repair has restored the structural properties with no remaining voids, delamination or other defects. Documentation and monitoring where detailed record of repair process including materials used, cure cycles, non-destructive testing results are maintained for future reference in compliance with safety standards. So, here we can see how rigorously a wind turbine blade is getting tested at a facility at National Wind Technology Center. Here, we can see the length of the blade of approximately 45 meters is tested for bending types of loads. Next, is the quality assurance for ongoing maintenance and performance monitoring.

Remote monitoring where, advanced remote monitoring systems allow for continuous data collection and analysis of wind turbines performance enable operators to identify potential issues early. This is a proactive approach which can reduce the downtime and maximize the turbine efficiency. Scheduled maintenance in this regard, regular maintenance schedule are essential for preventing failure and ensuring optimal performance. These schedules include tasks such as blade inspection, gearbox lubrication, electrical system checks are performed according to specific time interval or based on operating hours. So, this type of ongoing maintenance and performance quality can lead to wind turbine condition monitoring and the data collected from these efforts can be used for machine learning for wind turbine condition monitoring, big data mining and predictive maintenance.

So, in the summary of this lesson that we have gone through today, we have looked at various type of damages in the wind turbine components. Then, we have looked at the various non-destructive testing techniques for damage assessment. We have looked at various repair and maintenance techniques for wind turbines. And lastly we have seen some of the predictive maintenance and data collection for continuous monitoring of wind turbine blades. So, in the next lesson which will be the last lesson for this course, we will summarize the complete course in which we will look at the summary of the gas turbine, steam turbine, hydro turbine and wind turbine from the perspective of their service conditions and mapping it to the materials which have been used and subsequently the manufacturing processes which have been used to manufacture these type of turbines.