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A REVIEW ON DEVELOPMENT OF STRUCTURAL HEALTH MONITORING SYSTEM FOR DAMAGE IDENTIFICATION IN WIND TURBINE BLADE

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Abstract*:*

This paper gives an outline of the experimental methods in health monitoring techniques applied to wind turbine blade. To identify, localize and determine the severity of damage, methods like acoustic emission, ultrasonic, vibration based, wavelet analysis, visual inspection, machine learning etc. are discussed. The discovery standards, improvement strategies, advantages and disadvantages of previously mentioned strategies are evaluated. It is observed that some of the damage identification techniques are not potentially used. This paper summarizes the potential of techniques to identify the damage occurred in wind turbine blade. These methods will be very useful to perform further research. The severity of damage can be determined by the techniques based on acoustic emission, ultrasonic and vibration. But to achieve more realistic results any two techniques can be combined.

Key Words: *Wind Turbine Blade, Frequency based method, FFT Analyzer, Static Analysis, dynamic test*

1.Introduction:

Wind energy is one of the main supportable and environmentally friendly power sources, which can be changed over into electrical energy for modern power supplies and family power utilizations. In 2012, wind energy adds up to 11% of the complete environmentally friendly power age, and means that public seriousness. With the increment of worldwide breeze energy limit establishment to 539 GW in 2017 and the pattern of expanding WTB sizes, severe difficulties are forced on their harm discovery and underlying wellbeing observing (SHM), where 19.4% of all the breeze turbine episodes in 2012 are inferable from cutting edge disappointments. Edges are the key and vital parts of a total breeze turbine power age framework working in unpleasant circumstances, which move wind power into electrical energy. They effect sly affect the general presentation of the breeze turbine and are exorbitant in produce (15-20% of the all-out cost) and upkee contrasted and different parts Composite materials, for example, fiber built up polymer (FRP) composites that are regularly used to create a WTB, have been ordinarily utilized in

WTBs to decrease the overall expense and weight, and to work on the strength, firmness, harm obstruction, adaptation to internal failure and administration life. Cutting edges of present-day breeze turbines are intricate, innovative constructions, and their expense comprises a critical piece of the whole wind-turbine cost. While working, the sharp edges are intensely stacked and presented to unforgiving weather patterns, particularly for seaward wind turbines.

2.Damage Detection Techniques:

The purpose of damage detection is to ensure that the damage can be monitored before it causes catastrophic incidents or disasters to the wind turbine. It is applied to ensure that the cutting edge is working in a decent condition and is as yet satisfying its capacities. Additionally, it is utilized to distinguish the underlying driver of the harm and along these lines advance powerful upkeep structural monitoring or material changes of WTBs are mainly based on strain measurement, acoustic emission, ultrasound, vibration, thermography, machine vision and others. Especially, detection techniques based on strain measurement [12].

2.1 Vibration :

Detection methods based on vibration focus on the monitoring of abnormal vibration caused by irregular oscillation, deformation occurrence and so on, and are concerned with vibration signals representing dynamic properties of WTBs, such as recurrence reaction and modular boundaries of the sharp edge structure , to recognize harms causing changes in these properties[13] Dislodging sensors, speed sensors and accelerometers are the significant kinds of sensors to catch vibration signals. The recurrence goes from low-recurrence, center recurrence and high-recurrence runs, and are utilized in the comparing vibration sensors, individually. [14] used vibration reaction information to an example recognizer on a 9 m CX-100edge to recognize the edge harm. Scrimps et al. [15] utilized horizontal vibration information from the nacelle and power exhibitions decrease to recognize ice gradual addition, and 13 breeze turbines were utilized to approve the productivity of the proposed approach. Uprisen et al.[16] concentrated on a harm distinguishing proof technique on underlying mode shapes with modular and wavelet investigation to identify and restrict a 1.2 m following edge debonding on a 34 m sharp edge. Oliveira et al. [17]

studied a damage identification method technique on underlying mode shapes with modular and wavelet investigation to identify and limit a 1.2 m following edge debonding on a 34 m cutting edge. Oliveira et al. [17] presented a vibration-based checking framework with the modular properties, which were equipped for observing sharp edge harms in both inland and seaward wind turbines. Dolin' ski et al. [28] utilized FEM and the laser checking vibrometer to decide the size and area of delamination in WTBs. Howell et al. [29] proposed an upgraded information driven vibration-based strategy utilizing multivariate harm delicate highlights removed from speed increase reactions for the harm recognition. Zhang et al. [30] utilized an arbitrary woods classifier to identify turbine sharp edge icing, by examining the information from a breeze ranch with consolidated vibration signals in an administrative control and information procurement framework. Colone et al. [31] proposed a strategy, which just depends on signal frequencies to identify the mass changes for WTBs. Furthermore, the methodology of measurable example acknowledgment was taken on. Hoell et al. [32] checked the primary wellbeing of WTBs by viewing autoregressive model coefficients as the harm highlights to work on the capacity of early harm recognition.

Benefits and inconveniences of the vibration-based discovery innovation are summed up in Table 5. Ecological and functional circumstances, for example, wind speed, the rotational speed of WTBs, temperature, surrounding stacking conditions, etc, may clearly impact the unique properties of the cutting edge, for example, normal recurrence, mode shape and damping [46-48]. The trouble and the examination focal point of the strategy is to recognize the vibration brought about by harms from the vibration brought about by natural and functional circumstances

Khalkar and Ramachandran [7], 2017, carried out systematic study on the free vibration of Euler-Bernoulli beam containing open edge transverse cracks. Two springs steel materials (EN 8 and EN 47) were considered. The effect of the top side cracks and bottom side cracks on the natural frequency of a cantilever beam was discussed. The natural frequency of a cracked case cantilever beam was investigated numerically using FE analysis software ANSYS.

2.2 Ultrasound:

Recognition strategies in view of ultrasound recognize reflected waves from the harm when the ultrasonic waves are sent through the material and got on inverse surfaces [18,19], as displayed in Fig.The ultrasonic innovation is one of the most broadly involved NDT methods in industry [20,18]. The strategy is reliant upon the proliferation and impression of versatile waves inside the sharp edge [21]. Explicit reflection, constriction, reverberation and transmission examples can be gotten relying upon the distinctions of the material or construction [22], along these lines, the size, area and other data of the harm can be assessed through these examples.[23]

The ultrasonic innovation was utilized widely for researching internal design harm (e.g., delamination, debonding, etc.) [15,24]. It can distinguish harms with a couple of millimeters long [12]. The transmission time demonstrates the harm position and the plentifulness evaluates the seriousness of the harm [21,25]. Inside and out data of the harm can be likewise gotten by utilizing the ultrasonic innovation, yet its prosperity was restricted by difficulties in signal handling, delayed procurement time and the need to contact with the surface [22]. These issues limit its application potential for the inspection of WTBs or other huge parts.

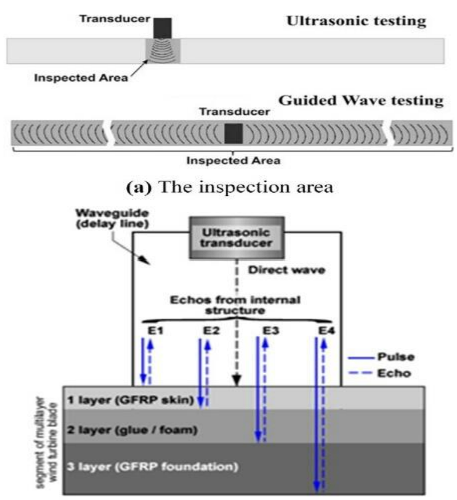


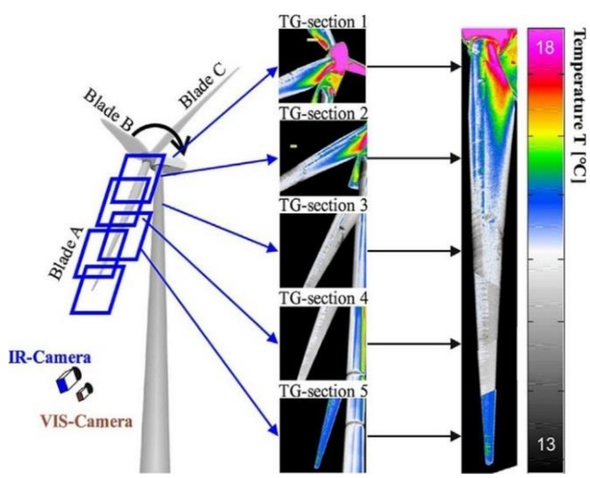
Fig.1 Principle of the pulse echo technique

fostered a computerized non-horrendous testing framework utilizing the beat reverberation ultrasound for in situ examination of WTB inward harms. Habibi et al. [33] joined UGWs and low-recurrence vibrations for ice evacuation on the composite sharp edge surface. Yin et al. [33] proposed a ultrasonic de-icing framework for WTBs, which was ended up being practical for de-icing purposes. Park et al. [26] formed an examining procedure for a non-contact laser ultrasonic estimation framework to work on the presentation of the WTB review, where coarse examining and thick checking were performed with a low/high spatial goal in various sizes of the tried cutting edge. Zuo et al. [34] introduced an original harm distinguishing proof calculation utilizing UGWs in view of 2-layered numerous sign characterization, which can be applied to perceive the turbine sharp edge harms. Shoja et al. [16] applied the directed wave for ice recognition of WTBs working in cool environment areas, with mathematical recreations and test approvals. Jiménez et al. [34] utilized sign handling (wavelet change) and AI (design acknowledgment) with directed waves to recognize and analyze the degrees of soil and mud on WTBs. Besides, Jiménez et al.

2.3 Thermography:

Detection methods based on in view of thermography focus on the identification of varieties in thermodynamic properties of the edge, which consider filtering enormous WTB surfaces [29,27]. Material harms of the edge can be estimated by temperature slopes non-damagingly, and the distinguished part with harms has higher temperature than the typical part [31]. Infrared based sensors or cameras are generally used to picture varieties in turbine sharp edge surface temperature [15,26]. Nonetheless, it isn't appropriate for issue identification at a beginning phase because of the sluggish temperature improvement [31]. A plan of the thermography method involving infrared-based camera as well as the thermogram results is displayed in Fig. 8. The outcome comprises of five sewed halfway thermograms, and the distinctions in temperature show the expected imperfections on the subsurface of WTBs. The temperature distinctions close to the center address the expected subsurface harms of the WTB yang et al. [36] finished up the current status and the utilization of infrared photography strategies to distinguish harms and evaluate the soundness of WTBs, and demonstrated that this sort of methods had not been generally utilized in industry. Galleguillos et al. [35] utilized the infrared thermography (IRT) and utilized automated ethereal frameworks (UAS), as a non-disastrous technique, to distinguish in-administration harms in a composite WTB. Muñoz et al. [36] proposed a clever methodology utilizing warm infrared radiometry for sharp edge icing identification with next to no actual contact. Doroshtnasiret al. [35] utilized thermography to recognize likely subsurface imperfections or harms in seaward wind ranches.

Fig.2



The activity can be performed from far off distances by an information handling calculation that is not the same as the normal thermographic examination technique on photographical thermographic pictures. Hwang et al. proposed a nonstop line laser thermography method and a consistent wave line laser thermography framework for WTB observing without annihilation. The framework capacities under turning conditions by creating warm waves and records the comparing wave engendering with an infrared camera.

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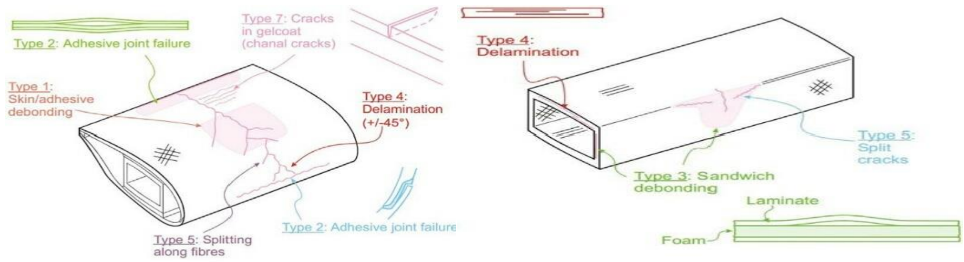
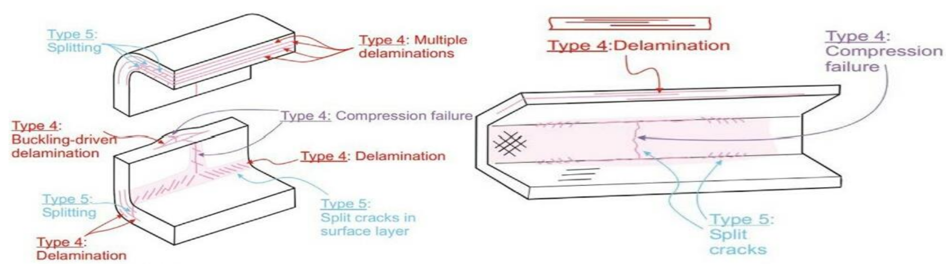
Sanati et al. researched two sorts of the thermography, including a uninvolved and dynamic beat thermography, and a stage warming also, cooling thermography
It can screen WTB absconds, where picture handling assumes a crucial part on the exact recognition of inner deformities. Notwithstanding, it is troublesome yet vital to feature the impact from the cutting edge harms on temperature and take out the impacts from different elements. Benefits and disservices of the thermography-based recognition innovation are surrendered.

2.4 Strain measurement:



3.1 Downwind skin damages 3.2 Main spar outer surface damages



3.3 Non-visible damages 3.4 Main spar internal surface damages

Fig.3

Identification strategies in light of strain estimation are applied to recognize minute changes long or disfigurements of the turbine cutting edge by utilizing strain sensors [21]. Edge structures twist under the applied burdens, and the distortion can be gotten by identifying the strain. Direct strain and shear strain are characterized and used in WTB review. The immediate strain is characterized as e ¼ x=l, and the shear strain is characterized as c ¼ x=d, where the meanings of the two kinds of the strain are shown in Fig. 2 [21]. Strain sensors are regularly introduced on a superficial level or inserted in the layers of the edge [12], which can by implication distinguish primary harms in WTBs through the extension or compression of the sharp edge brought about by temperature or strain variety [41]. Also, strain estimation enjoys the benefit that it can ceaselessly screen the turbine edge for extensive stretches of time [14], however the precision and reasonableness of strain estimation are subject to the distance between the area of the sensor and the harm
Contrasted and FBGs, strain measures don't show recognizable benefits that FBGs can be unreservedly and straightforwardly implanted into the materials, and engraved into one single optical fiber. Then again, strain measures should be mounted on the WTB surface and somewhere around two wires are required [40]. FBGs are ended up being more appropriate for strain estimation in WTBs than strain checks [7,], and are feasible to be installed into cutting edge structures during the assembling system [40]. Albeit optical fiber sensors have high responsiveness, little size, light weight, high exhaustion opposition, wide scope of working temperature, and are feasible to be implanted in composites, etc [40], their application potential being shown in WTBs observing is restricted due to its greater expense [9,14].

sierra-Pérez et al. proposed a clever strategy in view of strain estimation progressively to recognize harms in WTBs, and example acknowledgment techniques were utilized to distinguish the imperfections and nonlinearities for the affirmation testing of WTBs. Wu et al. [39] introduced a clever strain sensor for WTB estimations with potential applications for slim plate designs and shells, which could create a 2-layered strain guide and diversion states of the surface for on-line state evaluation. Tian et al. proposed an element data combination technique to intertwine the data of Chi-square dispersion from FBGs to identify the harms on WTBs, and the practicality of this proposed strategy has been checked with a strain sensor framework. Laflamme et al. [40] formed a methodology for harm recognition making out of delicate elastomeric capacitor (SEC) with low expenses to quantify surface strains, which shown the conceivable capability of restriction, harm location and visualization for WTBs. Lee et al.

Sierra-Pérez et al. [43] proposed an original approach in light of strain estimation progressively to distinguish harms in WTBs, and design acknowledgment techniques were utilized to identify the deformities and nonlinearities for the affirmation testing of WTBs. Wu et al. [43] introduced an original strain sensor for WTB estimations with potential applications for dainty plate

constructions and shells, which could create a 2-layered strain guide and avoidance states of the surface for on-line state appraisal. Tian et al. [44] proposed an element data combination technique to meld the data of Chi-square circulation from FBGs to recognize the harms on WTBs, and the possibility of this proposed strategy has been confirmed with a strain sensor framework. Laflamme et al. [45] formed a procedure for harm recognition making out of delicate elastomeric capacitor (SEC) with low expenses to quantify surface strains, which shown the conceivable capability of confinement, harm identification and guess for WTBs. Lee et al. [46] proposed an observing framework for diversion location of WTBs with strain sensors and a calculation in view of the relationship between's the avoidance and the strain. The creators likewise proposed a checking framework without wires to screen vibration reactions of an in-administration sharp edge. Aihara et al. [47] fostered an on-line observing framework for WTBs by appending a couple of strain checks at the base of an edge to assess the diversion with the deliberate strain, and the detecting results were gotten by a remote association. Schroeder et al. [48] carried out ceaseless burden observing of WTBs in activity by utilizing optical FBGs, and showed that the outcomes can give direction to edge improvement later on. Ramakrishnan et al.

2.5 Machine Learning:

Identification techniques in light of machine vision use successions of 2-layered/3-layered pictures from various areas and viewpoints to acquire the data of the objective item, whose standard is like the stereoscopic perspective on human vision [28]. As of late, with the incredible improvement of software engineering and optics gadgets, the machine vision-based methodology has been applied often for SHM in harm discovery, dynamic recognizable proof, etc [22,3]. This technique can further develop the identification exactness and proficiency, still up in the air by picture handling calculations. Moreover, machine vision-based strategies are less impacted by the ecological elements than other discovery techniques. Additionally, this technique has been

Fig.4

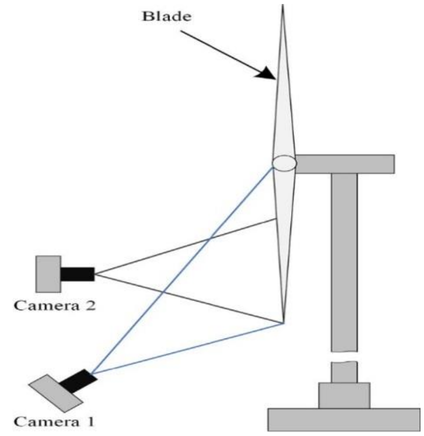


Fig.5

ended up being a productive and financially savvy strategy in observing turbine edges during activity, and is the best way to identify low tension surface clasping [34]. Johnson et al. [34] built a sound system video grammars framework to screen the airfoil shape and the surface movement of the turbine cutting edge. Yang et al. [37] fostered a videometric method to recognize sharp edge distortions and comprehend the underlying conduct of WTBs in the huge scope range during activity. Wu et al. talked about the vision-based way to deal with identify enormous scope designs like turbine edges, and the underlying removal can be extricated by recording and examining picture groupings with picture handling methods, like edge recognition calculations, matching calculations, also others. Makhloufi et al. [41] introduced a PC vision-based strategy to gauge ice collection on WTBs in operation, where an advanced camera was utilized and calculations on picture handling were created. Poozesh et al. utilized 3-layered advanced picture connection (3D DIC) to catch full-field strain over enormous region of a WTB, where a couple of sound system cameras were used to acquire the surface math, distortion and strain on the sharp edge surface. With the examination establishment, Poozesh et al. [30] likewise proposed a multi-camera estimation framework with customary 3D DIC and 3-layered guide following methodologies toward measure the whole surface of WTBs. It is fundamental to naturally identify harms for WTB support. Stockland et al. introduced an independent machine vision approach utilizing an automated ethereal vehicle (UAV) for acknowledgment and following a breeze turbine, as well as the sharp edges, and Hough line change was utilized as the acknowledgment calculation and a Kalman channel was applied for following. Wang et al. proposed an information driven programmed break identification structure for WTBs in light of UAV-taken pictures by utilizing Haar-like elements. Babu et al. [42] depicted a break acknowledgment strategy in view of text based elements to get mechanized investigation for early breaks in WTBs. Moreno et al. [42] presented a profound learning vision-based methodology utilizing a camera mounted on a mechanical framework to naturally screen each piece of the sharp edge surface. Harms, for example, effect of sun beams, wear and breaks, can be recognized. Vision-based approaches have been regularly utilized with other checking methods [25]. Daud et al. utilized visual nondestructive wellbeing checking and the piezoelectric sensor to evaluate the harm of the cutting edge brought about by lightning strikes. Yang et al.[42].

3.Discussion:

Wind Turbine Blades can have various types of damages. The blades could be damaged internally or externally. Some damage types are classified in the table shown below.

3.1 Typical damage types for WTBs:

No.	Damage types for WTB	Internal/Outer
1	Skin/adhesive or main spar/adhesive layer debonding	Outer
2	Adhesive joint failure between skins	Outer
3	Sandwich panel face/core debonding	Outer
4	Delamination driven by a tensional or a buckling load	Internal
5	Fiber failure in tension, laminate failure in compression	Internal/Outer
6	Skin/adhesive debonding induced by buckling	Outer
7	Cracks or debonding of the gel-coat	Outer

3.2 Comparison of different damage detection techniques for WTBs:

Technique	Types of monitoring	On-line available	Cost	Precision	Reference
Strain measurement	Embedded	Yes	Low/High	= 1 cm	[11]
Acoustic emission	Contact	Yes	High	<1	[12]
Ultrasound	Contact/Non-contact	Yes	High	= 1 cm	[18]
Vibration	Contact/Non-contact	Yes	Medium	<1	[22]
Thermography	Non-contact	Yes	High	3–5 mm	[35,37]
Machine vision	Non-contact	Yes	Low	= 1 cm	[38]

3.3 Comparison in SHM techniques:

Sr. No.	**SHM Technique**	**Ability to detect Damage**	**Associated Cost**	**Sensitivity**	**Contact Type**	**Ref**
1	Acoustic Emission	Very small, Location and size of damage	Expensive	High	Contact	[44]
2	Vibration based	Moderate size	Cheap	Moderate	Contact	[44]

3	Fiber Optics	Adhesive failure	Expensive	High	Contact	[44]
4	Strain Measurement	Small	Moderate	Moderate	Contact	[44]
5	X ray	Location and Size	-	-	Non - Contact	[44]
6	Ultrasonic	Location and Size (Delamination)	Moderate	High	Contact	[44]
7	Digital Image Correlation	full-field identification	-	-	Non-Contact	[45]
8	Shearography	full-field identification	-	-	Non-Contact	[45]
9	Thermal Imaging	full-field identification	Expensive	High	Non-Contact	[45]
10	Pattern Recognition	full-field identification	Moderate	High	Non-Contact	[46]

4. Conclusion:

1. The productivity of the framework relies on the plan of generator or spinner since it fosters the turning vortex, subsequently essential spotlight will be on its plan.
2. Nobody have done the examination on the quantity of cuts on spinner so here we will plan and foster three quantities of spinner with two, three and four cuts in it and check for its effectiveness.
3. Gaussian Processes can be utilized to give more accurate results in determining the dynamic response of wind turbine blade.
4. It is observed that the strain sensors can be used to determine dynamic response of wind turbine blade analysis.
5. The outcomes showed the fruitful execution of this strategy by which the separate harms were recognized ahead of basic disappointment.
6. Computation efforts can be reduced in determining solution to equation of motion.
7. For more accurate results two or more damage identification techniques can be combined.

5. REFERENCES:

[1] Zengshun Chen, Xiao Zhou, Xu Wang, Lili Dong, Yuanhao Qian – "Deployment of a Smart Structural Health Monitoring System for Long-Span Arch Bridges: A Review and a Case Study", Sensors 2017, 17, 2151

[2] O. S. Salawu – "Detection of structural damage through changes in frequency a review", Engineering Structures, Vol. 19, No. 9, pp. 718-723, 1997

[3] A.H. Gandomi, M., G. Sahab, A. Rahaei, M. Safari Gorji – "Development in Mode Shape-Based Structural Fault Identification Technique", World Applied Sciences Journal 5 (1): 29-38, 2008

[4] Kaushar H. Barad, D. S. Sharma, Vishal Vyas – "Crack detection in cantilever beam by frequency based method", Procedia Engineering 51 (2013) 770

[5] Mahdi Heydari, Alireza Ebrahimi, Mehdi Behzad – "Forced vibration analysis of a Timoshenko cracked beam using a continuous model for the crack", Engineering Science and Technology, an International Journal xxx (2014) 1

[6] Jorg Wauer – "On the dynamics of cracked rotors: A literature survey ", ASME Book No AMR067, Appl Mech Rev vol 43, no 1, Jan 1990

[7] Mahdi Heydari, Alireza Ebrahimi, Mehdi Behzad – "Forced vibration analysis of a Timoshenko cracked beam using a continuous model for the crack", Engineering Science and Technology, an International Journal xxx (2014) 1

[8] O. S. Salawu and C. Williams – "Review of full-scale dynamic testing of bridge structures", Engg Struct. 1995, Volume 17, Number 2 113 – 121

[9] D. Li, S.C.M. Ho, G. Song, L. Ren, H. Li, A review of damage detection methods for wind turbine blades, Smart Mater. Struct. 24 (3) (2015) 033001.

[10] B.F. Sørensen, E. Jørgensen, C.P. Debel, H.M. Jensen, T.K. Jacobsen, K. Halling, et al., Improved design of large wind turbine blade of fibre composites based on studies of scale effects (phase 1). summary report.

[11] Y. Yan, L. Cheng, Z. Wu, L. Yam, Development in vibration-based structural damage detection technique, Mech. Syst. Signal Process. 21 (5) (2007) 2198–2211.

[12] W. Qiao, D. Lu, A survey on wind turbine condition monitoring and fault diagnosis-part i: components and subsystems, IEEE Trans. Industr. Electron. 62 (10) (2015) 6536–6545.

[13] A. Abouhnik, A. Albarbar, Wind turbine blades condition assessment based on vibration measurements and the level of an empirically decomposed feature, Energy Convers. Manage. 64 (2012) 606–613.

[14] Z. Hameed, Y. Hong, Y. Cho, S. Ahn, C. Song, Condition monitoring and fault detection of wind turbines and related algorithms: a review, Renewable Sustain. Energy Rev. 13 (1) (2009) 1–39.

[15] G.A. Skrimpas, K. Kleani, N. Mijatovic, C.W. Sweeney, B.B. Jensen, J. Holboell, Detection of icing on wind turbine blades by means of vibration and power curve analysis, Wind Energy 19 (10) (2016) 1819–1832.

[16] M.D. Ulriksen, D. Tcherniak, P.H. Kirkegaard, L. Damkilde, Operational modal analysis and wavelet transformation for damage identification in wind turbine blades, Struct. Health Monit. 15 (4) (2016) 381–388.

[17] G. Oliveira, F. Magalhães, Á. Cunha, E. Caetano, Vibration-based damage detection in a wind turbine using 1 year of data, Struct. Control Health Monitor. 25 (11) (2018) e2238

[18] C.C. Ciang, J.R. Lee, H.J. Bang, Structural health monitoring for a wind turbine system: a review of damage detection methods, Meas. Sci. Technol. 19 (12) (2008) 122001.

[19] G. Ye, B. Neal, A. Boot, V. Kappatos, C. Selcuk, T.H. Gan, Development of an ultrasonic ndt system for automated in-situ inspection of wind turbine blades, in: EWSHM-7th European Workshop on Structural Health Monitoring, 2014

[20] P. Tchakoua, R. Wamkeue, T.A. Tameghe, G. Ekemb, A review of concepts and methods for wind turbines condition monitoring, in: Computer and Information Technology (WCCIT), 2013 World Congress on, IEEE, 2013, pp. 1–9.

[21] P. Schubel, R. Crossley, E. Boateng, J. Hutchinson, Review of structural health and cure monitoring techniques for large wind turbine blades, Renewable Energy 51 (2013) 113–123.

[22] I. Amenabar, A. Mendikute, A. López-Arraiza, M. Lizaranzu, J. Aurrekoetxea, Comparison and analysis of non-destructive testing techniques suitable for delamination inspection in wind turbine blades, Compos. Part B: Eng. 42 (5) (2011) 1298–1305.

[23] J.K. Lee, J.Y. Park, K.Y. Oh, S.H. Ju, J.S. Lee, Transformation algorithm of wind turbine blade moment signals for blade condition monitoring, Renewable Energy 79 (2015) 209–218.

[24] W. Qiao, D. Lu, A survey on wind turbine condition monitoring and fault diagnosis-part ii: Signals and signal processing methods, IEEE Trans. Industr. Electron. 62 (10) (2015) 6546–6557.

[25] K. Katnam, A. Comer, D. Roy, L. Da Silva, T. Young, Composite repair in wind turbine blades: an overview, J. Adhesion 91 (1–2) (2015) 113–139

[26] B. Yang, L. Zhang, W. Zhang, Y. Ai, Non-destructive testing of wind turbine blades using an infrared thermography: a review, Materials for Renewable Energy and Environment (ICMREE), 2013 International Conference on, vol. 1, IEEE, 2014, pp. 407–410.

[27] 7] A.A. Jiménez, C.Q.G. Muñoz, F.P.G. Márquez, Dirt and mud detection and diagnosis on a wind turbine blade employing guided waves and supervised learning classifiers, Reliab. Eng. Syst. Saf.

[28] Ł. Dolin´ ski, M. Krawczuk, A. _ Zak, Detection of delamination in laminate wind turbine blades using one-dimensional wavelet analysis of modal responses, Shock Vibration (2018)

[29] S. Hoell, P. Omenzetter, Sequential projection pursuit for optimised vibration-based damage detection in an experimental wind turbine blade, Smart Mater. Struct. 27 (2) (2018) 025007

[30] L. Zhang, K. Liu, Y. Wang, Z. Omariba, Ice detection model of wind turbine blades based on random forest classifier, Energies 11 (10) (2018) 2548

[31] L. Colone, M. Hovgaard, L. Glavind, R. Brincker, Mass detection, localization and estimation for wind turbine blades based on statistical pattern recognition, Mech. Syst. Signal Process. 107 (2018) 266–277.

[32] S. Hoell, P. Omenzetter, Optimal selection of autoregressive model coefficients for early damage detectability with an application to wind turbine blades, Mech. Syst. Signal Process. 70 (2016) 557–577.

[33] H. Habibi, L. Cheng, H. Zheng, V. Kappatos, C. Selcuk, T.H. Gan, A dual de-icing system for wind turbine blades combining high-power ultrasonic guided waves and low-frequency forced vibrations, Renewable Energy 83 (2015) 859–870

[34] H. Zuo, Z. Yang, C. Xu, S. Tian, X. Chen, Damage identification for plate-like structures using ultrasonic guided wave based on improved music method, Compos. Struct. 203 (2018) 164–171.

[35] M. Doroshtnasir, T. Worzewski, R. Krankenhagen, M. Röllig, On-site inspection of potential defects in wind turbine rotor blades with thermography, Wind Energy 19 (8) (2016) 1407–1422

[36] B. Yang, L. Zhang, W. Zhang, Y. Ai, Non-destructive testing of wind turbine blades using an infrared thermography: a review, Materials for Renewable Energy and Environment (ICMREE), 2013 International Conference on, vol. 1, IEEE, 2014, pp. 407–410.

[37] W. Yang, P.J. Tavner, C.J. Crabtree, Y. Feng, Y. Qiu, Wind turbine condition monitoring: technical and commercial challenges, Wind Energy 17 (5) (2014) 673–693.

[38] N. Beganovic, D. Söffker, Structural health management utilization for lifetime prognosis and advanced control strategy deployment of wind turbines: an overview and outlook concerning actual methods, tools, and obtained results, Renewable Sustain. Energy Rev. 64 (2016) 68–83

[39] F. Besnard, L. Bertling, An approach for condition-based maintenance optimization applied to wind turbine blades, IEEE Trans. Sustain. Energy 1 (2) (2010) 77–83.
[40] J. Sierra-Pérez, M.A. Torres-Arredondo, A. Güemes, Damage and nonlinearities detection in wind turbine blades based on strain field pattern recognition. FBGS, OBR and strain gauges comparison, Compos. Struct. 135 (2016) 156–166
[41] X. Ye, Y. Su, J. Han, Structural health monitoring of civil infrastructure using optical fiber sensing technology: s comprehensive review, Sci. World J. 2014 (2014) 1–4
[42] C. Babu, K. Meena, Structural health monitoring & fault detection in wind turbine using image processing techniques, TAGA J. 14 (2018) 1967–1977
[43] J. Wu, C. Song, H.S. Saleem, A. Downey, S. Laflamme, Network of flexible capacitive strain gauges for the reconstruction of surface strain, Meas. Sci. Technol. 26 (5) (2015) 055103.
[44] S. Tian, Z. Yang, X. Chen, Y. Xie, Damage detection based on static strain responses using FBG in a wind turbine blade, Sensors 15 (8) (2015) 19992– 20005.
[45] S. Laflamme, L. Cao, E. Chatzi, F. Ubertini, Damage detection and localization from dense network of strain sensors, Shock Vibr. (2016)
[46] K. Lee, A. Aihara, G. Puntsagdash, T. Kawaguchi, H. Sakamoto, M. Okuma, Feasibility study on a strain based deflection monitoring system for wind turbine blades, Mech. Syst. Signal Process. 82 (2017) 117–129.
[47] A. Aihara, T. Kawaguchi, N. Miki, T. Azami, H. Sakamoto, M. Okuma, A vibration estimation method for wind turbine blades, Exp. Mech. 57 (8) (2017) 1213–1224.
[48] K. Schroeder, W. Ecke, J. Apitz, E. Lembke, G. Lenschow, A fibre Bragg grating sensor system monitors operational load in a wind turbine rotor blade, Meas. Sci. Technol. 17 (5) (2006) 1167.