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Wireless Sensors for Wind Turbine Blades Monitoring

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Abstract. The most common defects in turbine blades may be faulty microscopic and mesoscopic appeared in matrix, no detected by classical nondestructive testing (i.e. using phased array sensors), broken fibers can also appear and develop under moderated loads, or cracks and delaminations due to low energy impacts, etc. The paper propose to present the results obtained from testing of glass fiber reinforced plastic used in the construction of the wind turbine blades as well as the monitoring of the entire scalable blade using wireless sensors placed on critical location on blade. In order to monitories the strain/stress during the tests, the determination of the location and the nature of defects have been simulated using FEM.

1. Introduction

In accordance with to growing concern on global warming, it is expected to use more clean energy including wind energy. The designs of large wind turbines (WT) are rapidly increasing in 21st century. So then, wind induced damages of WT are increasing particularly in sever wind storm dominant region [1]. EU studies the possibility to update air pollution standards for thermal power station based on coal, in the conditions in which this type of installation represent the biggest source of sulfur dioxide and mercury, nitrogen oxides, arsenic, lead and cadmium emissions. Thus, the market for electrical energy obtained by harvesting wind power is expanding. In these conditions, in order to increase the power of turbine, wind turbine producers use glass fiber reinforced plastics in the construction of wind turbine blades (WTB) because these allow due to low weight, the increase of blade's dimensions [2,3]. Nondestructive testing (NDT) techniques for in-service inspection and determination of high risk degradation regions of blades are growing, function of the type and blade dimension, being based on numerous studies and researches, function on the type and the size of the WT [2]. The NDT method must be carried out both during the fabrication process as well as during the functioning of the blades, first for the decreasing of fabrication and maintenance costs and for reduced downtime. The blades are usually subject to random and complex mechanical stresses. Condition monitoring can be carried up using thermography [4] and fatigue crack detection performance can be done [5]. Implementing a process of fault detection and characterization of structures is refers as Structural Health Monitoring (SHM) [6]. The SHM (e.g. vibration monitoring and damage detection of wind blade) process involves the observation of a system over time using periodically sampled dynamic response measurements from an arrangement of sensors, the extraction of damage-sensitive features from these features to determine the current state of system health [7-11]. In order to decrease the fabrication and maintenance costs, as well as for avoiding unproductive time, NDT is required both during fabrication and in-service. Starting from the scheme presented in figure 1, flaws mentioned above must be detected and evaluated by NDT methods with good probability of detection (POD) under high reliability coefficient.

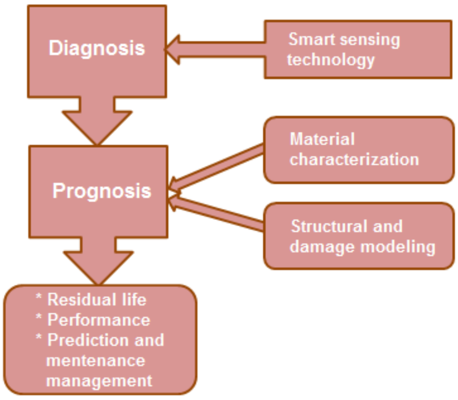

Figure 1. Structural Health Monitoring (SHM) principle.

Wireless sensors (WRS) are very attractive for SHM applications [12,13]. The last years have brought different wireless technologies that can be used for structural damage detection. This includes radio-frequency identification (RFID) technology that has been proposed for a wireless damage detection platform in civil engineering application [14-16]. RFID tag sensors provide identification data and monitor of physical parameters of tagged objects without having an active sensor in the tag circuitry [17,18]. The RFID tag sensor has distinguished impact in research publication field, economic and social areas. To this day, a passive, printable, mass deployable, low cost, environmentally RFID tag sensor has not been reported for monitoring the sensing parameters.

Passive RFID systems consist of an active read out device (reader) and one or several passive tags. They are used for the wireless identification of objects with a tag attached to them. Within this tag there is a microcontroller with memory where identifiers and supplementary information can be provided. The fundamental characteristic of passive RFID sensor is that the involved tags is full passive, gathering all their energy from a magnetic or electromagnetic field emitted by the reader [19-21]. The exclusiveness of RFID sensor compared reported studies are as follows:

I. data ID and sensing information are in both magnitude and phase spectrum;
II. a single tag has multiple parameter sensing capabilities and
III. RF sensing is incorporated using metamaterials rather than external sensors or lumped components in the tag circuitry.

The paper presents the results of testing of a WTB, in static conditions, using WRS embedded within in order to monitor possible damages that further can be transformed into flaws. To determine the righteous of solutions, reliability of correct diagnosis probability, prognosis, and evaluation of residual lifetime and maintenance management, a scalable WTB has been constructed, that had the scaled dynamics of a full scale blade as well as enough sensors for measurements as well as monitoring. The maximum stress zones [22] and damage evolution and remnant stress [23] have been determined using Finite Element Modelling (FEM). The results of complex mechanical tests, performed on scalable WTB models (in our case a blade of 1750 mm length) are used to give efficiency to monitoring strategy.

2. SHM based on transducers. Experimental set-up

The passive WRS designed to monitor stress/deformation status have as sensitive element a special type of MM, that follows the relative displacement (compression or tension) of its components due to an impact and can develop slows or either fast. The ratio of relative displacement to the structure

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length allows the calculation of materials deformation and the ratio of stress at deformation provides the elastic modulus which is an intrinsic property of the structures materials. Thus, the measurement of relative displacement provides critical information on the force presented on material. In function of type and geometrical dimensions, the sensor has the resonance frequency in the range of RF and microwaves.

In order to obtain the best sensor with MM for monitoring the GFRP structure, a sensor which allows the determination of resonance frequency displacement at the changing of dielectric properties from the sample has been developed. The system consist in a RFID reader and a RFID tag (figure 2), the tag including the sensor and the integrate circuit. When the effort is small, the resonance frequency modifies almost linear in function of effort, meaning that the effort can be determined if the resonance frequency is measured. The RFID tag antenna assures that the interrogation frequency shall be equal with the one of RFID tag to obtain perfect matching of impedance between antenna tag and IC chip. The interrogation range is one the important factors for LC passive WRS. The smallest amount of energy must be transmitted toward reader to activate RFID tag, meaning that the transmitted power threshold reach minimum value at resonance frequency. The RFID tag is bonded to the WTB structure subdued to loadings.

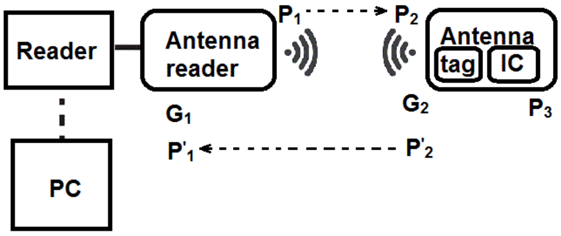


Figure 2. Wireless sensor system principle.

The SHM of WTB is characterized by sensors network around the blade to detect and locate any occurring damage. Taking into account the efficacy of the method and *a priori* knowledge about WTB, the sensors are distributed according to the most expected damage area, aiming the minimizing of the sensors number (figure 3).

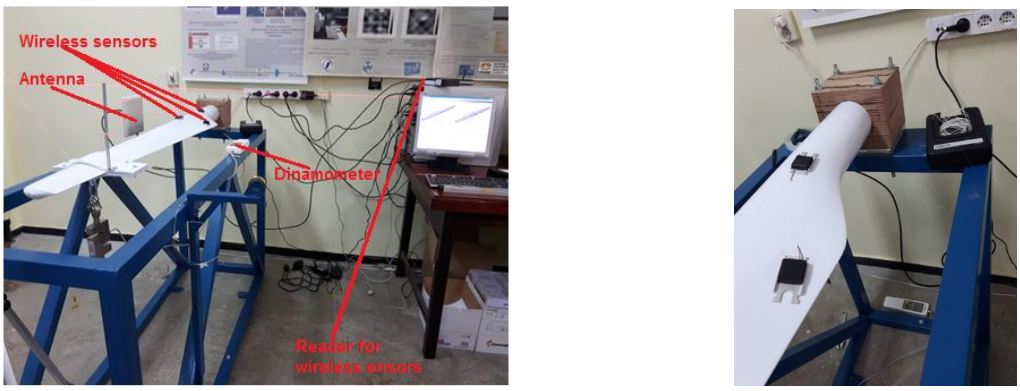


Figure 3. Testing stand and experimental set-up for WRS measurements.

The blade has been realized from E-glass/epoxy EPIKOTE Resin MGS LR 385 composite. The leading edge is straight and the trailing edge conical for an easy construction. The profile follows NACA airfoil. For increased structural strength and stiffness at 0.286R (R- the total length of distance between the center of rotor and the tip of blade), the same NACA has been applied both for the upper surface and lower surface, keeping the aerodynamically performances of the blade's tip. The profiles between 0.268R and tip were linear interpolated. A compromise has to be found between high-resolution and long propagation distance. The results are obtained at preliminarily testing of a scalable WTB, in laboratory, using passive RFID - WRS as uni-dimensional displacements sensor.

3. Wireless sensors (WRS) and FEM simulation

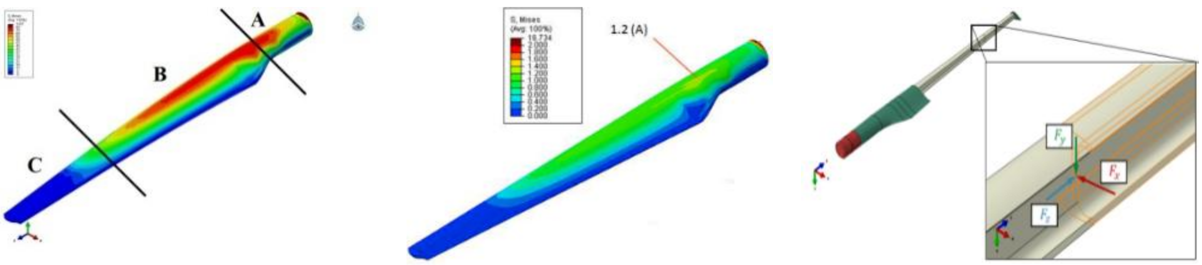
The passive WRS designed to monitory stress/strain status have as sensitive element a special type of metamaterial (MM), that follows the relative displacement (compression or tension) of its components due to an impact and can develop slows or either fast. The measurement of strain provides critical information on the force presented on material. In specific construction as 2D geometry on flexible support, copper split ring resonators can be used as stress/strain sensors [24,25]. In function of type and geometrical dimensions, the sensor has the resonance frequency in the range of RF and microwaves. The quality factor of the equivalent circuit has value in the range of tens or hundreds. MM presents resonant properties and around resonance frequency displays unusual properties. The inductance and the capacitance are given by [24].

In order to obtain the best sensor with MM for monitoring the glass fiber composite structure, a sensor which allows the determination of resonance frequency displacement at the changing of dielectric properties from the sample has been developed. The system consist in a RFID reader and a RFID tag [25], the tag including the sensor and the integrate circuit. When the sensor detect a modification of the strain ε, the frequency is

$$f_r^{'} = \frac{c}{4(1+\varepsilon)(L+\Delta L)\sqrt{\varepsilon_r}} = \frac{f_r}{1+\varepsilon} \approx f_r(1-\varepsilon) \tag{1}$$

Thus, when the load is small, the resonance frequency modifies almost linear with load, the load can be determined if the resonance frequency is measured. The RFID tag antenna assures that the interrogation frequency f shall be equal with the one of RFID tag to obtain perfect matching of impedance between antenna tag and IC chip. The smallest amount of energy must be transmitted toward reader to activate RFID tag, the transmitted power threshold (measured through the reader) reach minimum value at resonance frequency.

The reader antenna (Figure 3) is fixed on the upper part of the stand, at 30 cm from the middle area of WRS placement locus. The antenna is connected to a logger reader coupled to PC by USB. The loading force is configured to have an increment of 243με at each step. The mean threshold of interrogation power (dBm) is read by logger reader at each loading step.



(a) (b) (c)

Figure 4. FEM simulation of WTB:(a) division of blade in critical regions; (b) Von Mises stress; (c) loading forces disposition.

WRS can assure and enhance the functioning of WTB due to the detection/monitoring properties, small dimensions and reduced weight, allowing the embedding them into the base material of the blade (being embedded at intersection of longeron with NACA profile, inside the WTB). In this structure, 3 WRS were placed along the central longitude of the blade, into critical points determined by FEM of blade under vibration. Figure 4a presents the division of the blade in critical regions, in Figure 4b is presented the result of simulation under a force F_x = 200N, producing the displacement of the tip with 1.59 mm.

The FEM model shown below takes into account the presence of the reinforcement structure, who's mass cannot be neglected, especially if one considers that the distance from the axis of rotation increase the inertia and can reduce the frequency associated with the first mode of vibration of WTB. Fortunately, the glass fibers employed makes the structure very rigid.

Three WRS sensors were placed in region with maximum critical points established by FEM, in region B at 307 mm, 362 mm and 406 mm from the hub fixing in stand. All the loadings are static.

4. Experimental results

The dependency strain-load for WTB in a loading-unloading cycle for three sets of experimental measurement is presented in figure 5. It can be observed the same linear dependency strain-load, even the existence of a remnant stress at force removal, indicating an accumulation of energy in WTB composite structure, preponderant in the resin. These stresses are relieving in relatively short time once with the material relaxation, so that the new tests are not influenced. The reader antenna (Figure 2) is fixed on the upper part of the stand, at 30cm from the middle area of WRS placement locus. The antenna is connected to a logger reader coupled to PC by USB. The loading force is configured to have an increment of 243με at each step. The mean threshold of interrogation power, in dBm, is read by logger reader at each loading step. Figure 6 plots the experimentally dependency strain-load for WTB into a cycle loading for the three WRS placed in different critical regions.

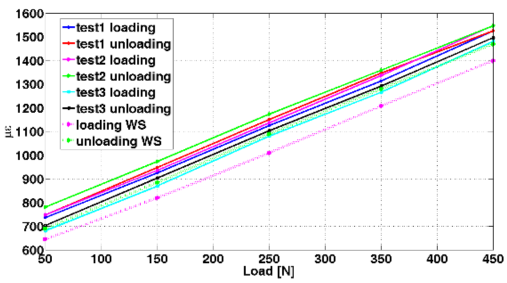


Figure 5. The dependence of strain vs. loadings.

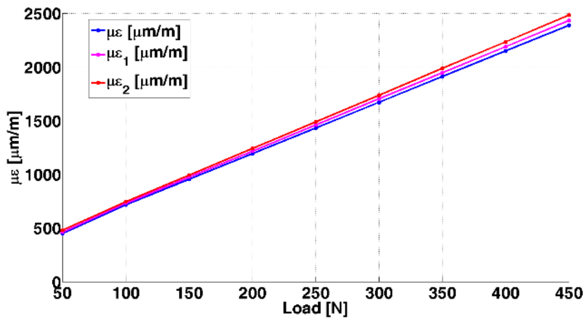


Figure 6. Signal delivered by the 3 wireless sensors for loading of WTB.

It can be observed that the strain has a practically linear dependency on to the applied load on all WRS with small difference on slopes. Although the sensors are not located at exactly the same location, a great resemblance has been found. The wireless sensors offer many advantages over traditional resistive strain gauges. These include remote sensing, easy installation, non-corrosive and lower maintenance cost. This shows that complementary technologies are a good alternative for structural strain monitoring.

5. Conclusions

A sensor wireless RFID for WTB monitoring based sensing platform has been development. The platform is maintenance free and can be used for the damage detection/monitoring in SHM applications. The sensing capability and the damage detection/monitoring performance of the system have been illustrated using detection in a GFRP composite. The results from the former experiment have been validated using numerical simulations. Practical applications demonstrates that, in order to avoid environmental disasters, it is necessary to establish diagnosis and prognosis methods, based on using information obtained from sensors constructed on known physical principles. The monitoring is close related with nondestructive evaluation and the trend is to obtain real time information. Scalable

WTB have been constructed and tested to loadings using WRS embedded in the maximum concentration stress zones. The sensors responses obtained in static conditions were analyzed following a linear tendency; even they were not placed in the same regions. The measurements show advantages as remote sensing, simple embedding, and easy interpretation. The tests were carried on scalable models because in the frame of the project that sustains the paper, the blades will be employed into a demonstrator to show the righteous of solutions, reliability of correct diagnosis probability, prognosis, and evaluation of residual lifetime and maintenance management.

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