PRZEGLĄD ELEKTROTECHNICZNY

Ukazuje się od 1919 roku **5'16**

Organ Stowarzyszenia Elektryków Polskich • Wydawnictwo SIGMA-NOT Sp. z o.o.

Tomasz CHADY[1], Ryszard SIKORA[1], Przemyslaw LOPATO[1], Grzegorz PSUJ[1], Barbara SZYMANIK[1], Krishnan BALASUBRAMANIAM[2], Prabhu RAJAGOPAL[2]

West Pomeranian University of Technology, Szczecin (1), Indian Institute of Technology, Madras (2)

doi:10.15199/48.2016.05.01

Wind Turbine Blades Inspection Techniques

***Abstract**. Wind turbines are complex composite structures, which condition should be constantly tested. In this paper the techniques which are already used or are implementable for non-destructive examination of wind turbine blades will be presented shortly. New electromagnetic techniques like active IR testing or terahertz imaging will be more widely presented and some exemplary results of inspections will be shown.*

Streszczenie**. Turbiny wiatrowe są złożonymi strukturami kompozytowymi, których stan powinien być stale badany. W niniejszym opracowaniu krótko przedstawiono metody nieniszczącego badania łopat turbin wiatrowych, które są obecnie stosowane lub są możliwe do wdrożenia. Nowe techniki wykorzystujące zjawiska elektromagnetyczne, jak aktywna inspekcja w podczerwieni, czy obrazowanie terahercowe, zostaną szerzej omówione. Zaprezentowane zostaną również przykładowe wyniki badań.* ***Metody nieniszczącego badania łopat turbin wiatrowych

Keywords: wind turbine blades, nondestructive testing, infrared testing, terahertz testing.
Słowa kluczowe: turbiny wiatrowe, defektoskopia, badania podczerwienią

Introduction

Because of higher environmental awareness of world society, share of wind energy in the total produced energy is steadily increasing. Thus more wind turbine installations will be deployed in the future, both on the land and offshore. Because of the size and exposure to weather conditions wind turbine blades (WTB) can be considered as the most critical part of wind turbine. That is the reason for development of accurate and easy to implement monitoring and testing techniques. Some of inspection methods can be utilized during production process, but their application in service would be much more difficult.

NDT techniques for wind turbine blades inspection

The wind turbine blade is a complex structure mostly made of glass-fiber, balsa wood (or plastic foam) and polymer adhesive. Thus material is nonhomogeneous and isotropic in case of both mechanical and electrical parameters. The photo of wind turbine blade cross section is presented in Fig. 1. Additionally, the surface is curved, there are big differences in wall thickness and there is no access to interior part of WTB. Accurate inspection of such structures causes many problems. There are several techniques that can be considered as applicable for non-destructive testing wind turbine blades [1]-[3]:

- visual inspection,
- infra-red thermography,
- ultrasonic testing,
- digital radiography,
- acoustic emission,
- tap testing,
- vibration analysis,
- microwave and terahertz techniques.

All of them are utilized for polymer laminates and sandwich composites inspection, thus their application in case of WTB production process is possible. The sensitivity and inspection time are the factors which determine the selection of suitable examination technique. Since blades are large-scale and on-tower, in service inspection needs much more effort. A new approach in industry is to use a climbing robot to scan the blades. In this paper pulsed terahertz technique THz and active infra-red thermography IRT will be considered for application is such systems.

Structural Health Monitoring SHM is utilized in order to constantly monitor the condition of WTB.

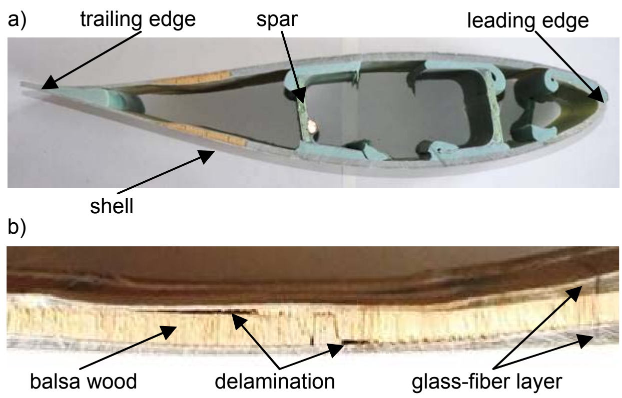

Fig.1. Wind turbine blade: a) view of cross section, b) typical defect – delamination between balsa wood core and glass-fiber laminates.

Terahertz imaging

Terahertz electromagnetic radiation enables non-invasive, non-ionizing and non-contact examination of dielectric structures such as wind turbine blades. The electromagnetic waves in terahertz frequency band are sensitive for changes of refractive index, thus any defect which noticeably disturbs refractive index, e.g.:

- void,
- delamination,
- inclusion,
- material inhomogeneities (fiber/matrix distribution),
- surface roughness,
- fiber waviness,

- internal interfaces between layers (in layered structures) can be detected. In most cases, defects are located by reflection or transmission imaging based on pulsed terahertz TDS (Time Domain Spectroscopy) [5]. The method is well suited for evaluation of layered materials (Fig. 2). Each interface between separate layers causes reflection of incident THz pulse and attenuation of transmitted one. Differences in delays of the propagated pulses and their echo (delayed layer reflections) enable characterization of the thicknesses and inner structure state. Very short pulses (order of picoseconds) contain wide frequency bandwidth (0.05 - 3 THz) and therefore it is possible to carry one single point broadband measurements.

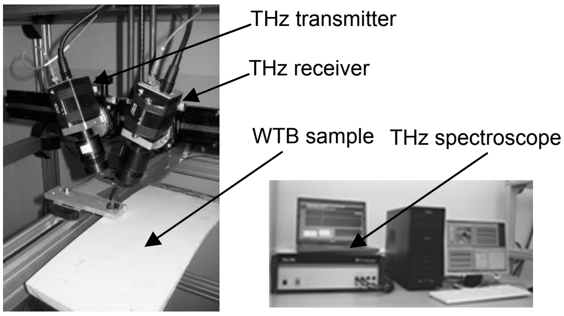

Fig.2. Photo of terahertz imaging system

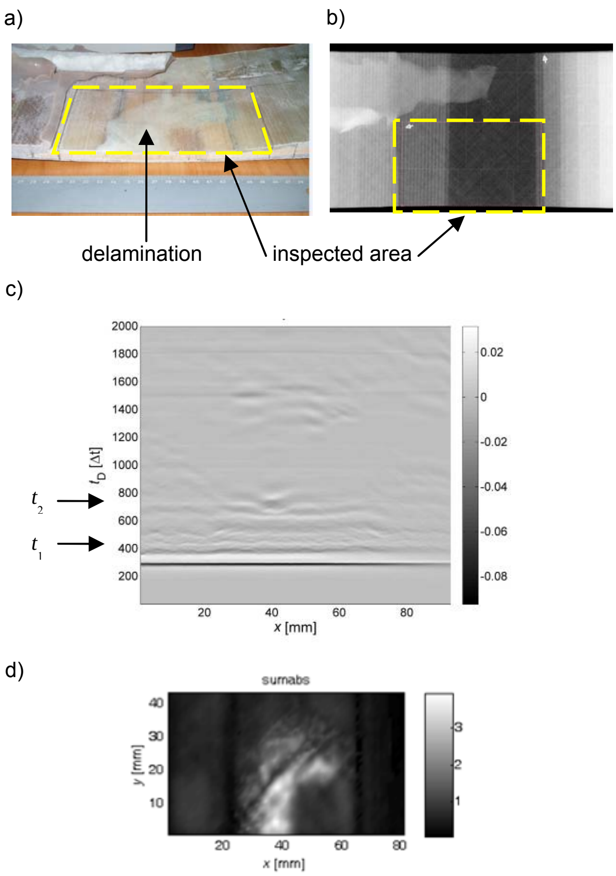

Fig.3. Results of wind turbine blade inspection: a) photo of the specimen, b) result of X-ray examination – no indication of defect in considered area, c) result of THz measurement – B-scan signal after registration, d) spatial distribution of proposed parameter p – white area is an indication of delamination.

Exemplary results of wind turbine blade inspection using pulsed terahertz technique are presented in Fig. 3. In case of utilized WTB sample (shown in Fig. 2 and 3a), the skin material consists of glass fiber reinforced resin and the core is made of balsa wood. The sample is defective - there are local delaminations between core and skin materials. One can see, the detection of this kind of defect using X-rays was not possible (Fig. 3b).

Signal after measurement was registered in order to reduce an influence of surface curvature on inspection results. Exemplary registered B-scan signal is presented in Fig. 3c. In next step for each measured (x,y) point, obtained time domain signal S(t) is processed and parametrized. Large amount of parameters can be calculated based on whole time domain response or just using time windows correlated with various depths or layers of the material being tested.

The following parameter enables accurate detection of the delamination between core and skin material in wind turbine blade:

(1) $$p = \int_{t_1}^{t_2} |S(t)| dt$$

where: t_1 - beginning of time window, t_2 – end of time window, p - proposed parameter, S(t) – time domain signal (A-scan). The distribution of proposed parameter is presented in Fig. 3d. The brighter area (higher values) corresponds to delaminated part of sample.

Pulsed terahertz inspection can be successfully applied during production phase. Because the examination is carried out point by point, its speed is low and testing of large areas (like in case of WTB) leads to long inspection times. This technique can be applied for detailed examination of suspected areas. Terahertz technique (including TDS) is still on early stage of development, thus the weight of time domain spectroscope is still a restriction for in service application, e.g. as climbing robot equipment.

Infrared thermography

Active infrared thermography is a relatively new NDT method, widely used in many applications. In this method the external energy source is used to induce thermal differences between the background and the region of interest in examined materials. The type of energy source is chosen for a specific application. In this paper the active infrared thermography with both: microwave and halogen lamp excitation is used to examine composite materials used in wind turbine blades.

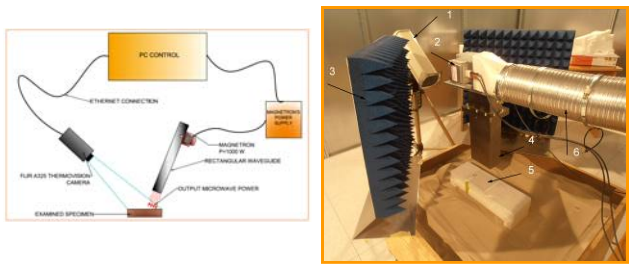

Fig. 4 Scheme and photo of experimental setup for active themography with microwave excitation. 1 - thermovision camera in Faraday cage, 2 - magnetron, 3 - 4 - rectangular waveguide, 5 - sample, 6 - cooling device

Fig. 4 shows the experimental setup for active thermography with microwave excitation. The magnetron (f=2.45 GHz, P=1000W) is used as the microwaves generator. The sample is located directly under the rectangular waveguide. The termovision camera, placed in Faraday cage for safety, is able to observe the process of microwave heating of the sample.

Fig. 5 shows the experimental setup for active themography with halogen lamp excitation. Two halogen lamps with power up to 2000W are used to evenly heat the sample. The thermovision camera is used for the observation of the temperature distribution at the sample surface.

Fig. 6 shows the exemplary result for turbine blade sample examination. The sample was heated using microwaves for 30 s. The sequence of thermograms was obtained with thermovision camera. Afterwards the simple image analysis was provided to obtain the resulting image showing the delamination.

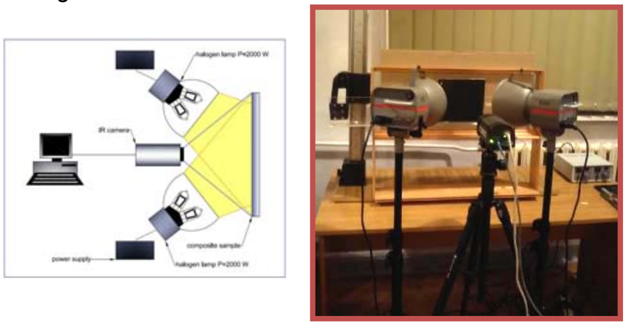

Fig. 5 Scheme and photo of experimental setup for active themography with halogen lamp excitation

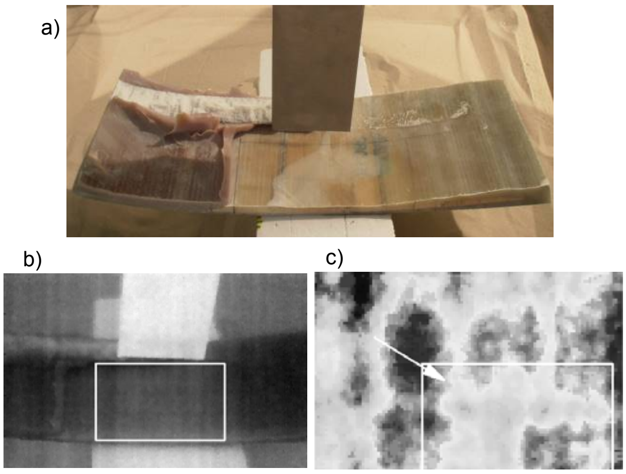

Fig. 6 The wind turbine blade sample examination, using microwave heating. a) the setup photo, b) the raw thermogram, c) result of examination, the delamination is marked

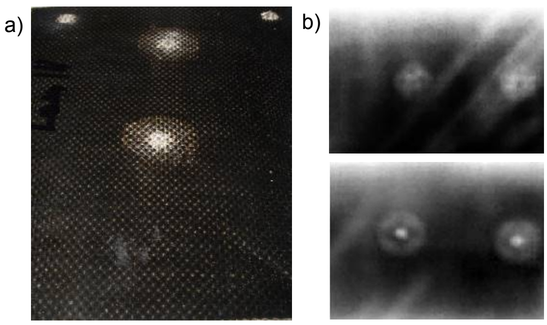

Fig. 7 The basalt with impact damages sample examination using halogen lamps heating. a) the setup photo, b) result of examination, the damages are visible

Fig. 7 shows the exemplary result for basalt composite sample examination. The sample was heated using halogen lamps for 60 s. The sequence of thermograms was obtained with thermovision camera observing both: heating and additional 60 s of natural cooling of the sample. Afterwards the simple image analysis was provided to obtain the resulting image showing the impact damages.
The active thermography with variety of energy sources may be used in composite materials used in wind turbine blades examination. The main advantage of this method is the possibility of rapid examination of the large scale structures.

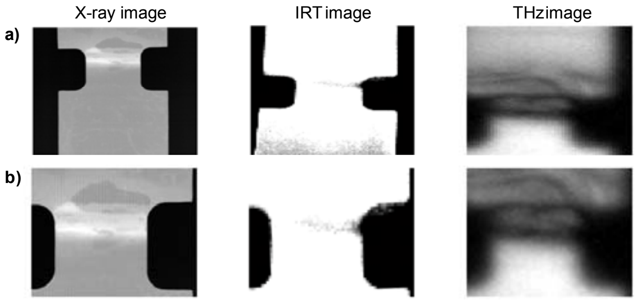

Fig 8. Selected results obtained for stress loaded sample: all methods results before (a) and after the registration process (b).

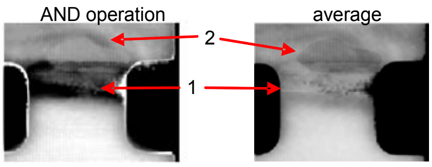

Fig 9. Results of the data fusion algorithms obtained for stress loaded sample; 1 - surface breakage indication, 2 – delamination indication.

Multi-source Data Fusion

The broad utilization of composite materials for manufacturing of wind turbines structures elements puts demand to develop new or adoption of already existing testing techniques. The selection of the most appropriate method for testing of composite materials depends on the nature of the fibers and the polymer matrix. However, no single NDT technique allows a full assessment of the material under test structure's integrity. In essence, each method presents some limits of detection and determination of the non-homogeneity of the material. In order to increase the probability of defect's detection and a proper evaluation of the material's structure, a need of fusion of data obtained from various testing methods is arising. Therefore in order to validate the possibility of utilization of different NDT techniques for detection of stress subjected composite materials the X-ray, active thermography and terahertz techniques were applied [4]. Selected measurements results obtained during the experiments are presented in Fig. 8a. Before the data fusion can be proceeded all acquired data must be transformed to common representation format. After the data registration process (Fig. 8b), low level fusion algorithms were performed in order to combine the information from multiple sources. The final integration of the images was performed utilizing algorithms based on AND and OR operation. The objective of low-level data fusion is to preserve the information supported by each method and present it in one common format. In case of AND operation only details of defects that are indicated by all methods are not reduced in fused result, while in case of OR algorithm information provided by all inspection methods are represented in the final result.

Conclusions

Because of: large scale of WTB, multilayered structure, just one side access, high thickness, non-automated production process, nondestructive inspection of WTB is still challenging and new methods are needed. THz time domain imaging is one of most informative EM technique of composites inspection (especially in case of layered medium) but its application is reduced (high inspection time in case of large structures). None of currently applied methods guarantees a very high efficiency of WTB defects detection. The application of X-ray, IRT and THz methods and merging the inspection results into common representation allows to increase the information level about the damage state of the composite material without losing the quality of the image. However it should be pointed that in industrial application low-level data fusion results can only be a tool in decision making procedure and require further processing or operator support.

This work was supported in part by European Commission project HEMOW: Health Monitoring of Offshore Wind Farms (reference: FP7-PEOPLE-2010-IRSES-GA-269202)..

***Authors**: Tomasz Chady {tchady@zut.edu.pl}, Ryszard Sikora {rs@zut.edu.pl}, Przemyslaw Lopato {plopato@zut.edu.pl}, Grzegorz Psuj {gpsuj@zut.edu.pl}, Barbara Szymanik {szymanik@zut.edu.pl}, West Pomeranian University of Technology, Szczecin, al. Piastow 17, Szczecin, Poland*
Krishnan Balasubramaniam {balas@iitm.ac.in}, Prabhu Rajagopal {prajagopal@iitm.ac.in}, Indian Institute of Technology, Madras, IIT-Madras, Chennai – 600036, India

REFERENCES

[1] Raišutis R., Jasiūnienė E., Šliteris R., Vladišauska A., The review of non-destructive testing techniques suitable for inspection of the wind turbine blades, *ULTRAGARSAS Journal,* 63 (2008), No. 1, 26-30
[2] Drewry M. A., Georgiou G. A., A review of NDT techniques for wind turbines, *Insight,* 49 (2007), No. 3, 137-141
[3] Zhang H., Jackman J., A feasibility study of wind turbine blade surface crack detection using an optical inspection method, *Proceedings of International Conference on Renewable Energy Research and Applications ICRERA 2013,* Madrid, Spain, 20-23 October 2013, 847-852
[4] G. Psuj, P. Baniukiewicz, P. Łopato, B. Szymanik, T. Chady, "Low Level Data Fusion of NDT Methods Results for Inspection of Stress Subjected Composite Materials", Studies in Applied Electromagnetics and Mechanics, Vol 39: Electromagnetic Nondestructive Evaluation (XVII), pp. 27-35, DOI: 10.3233/978-1-61499-407-7-27
[5] Mittelman D. M., Gupta M., Neelamani R., Baraniuk R. G., Rudd J. V., Koch M., Recent advances in terahertz imaging, *Applied Physics, Lasers and Optics*, **B 68** (1999), 1085 – 1094.