Ultrasonic NDT of wind turbine blades using contact pulse-echo immersion testing with moving water container

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Abstract

Wind turbine blades are complicated objects for inspection because they have a curved surface, are multi-layered, have variable thickness and are made from anisotropic materials. Ultrasonic contact pulse-echo immersion testing with moving water container has been selected for inspection of wind turbine blades, because this type of the inspection can be performed having access just from the one side of the wind turbine blade. The ultrasonic contact pulse-echo immersion testing technique with two types of ultrasonic transducers mounted into a moving water container was used for investigation of the artificial internal defects in a wind turbine blade. These defects (diameter 81 mm, 49 mm and 19 mm) were made on the internal side of the main spar. The contact pulse-echo immersion testing (using a moving water container) of the wind turbine blade was performed using two different transducers: focused 2.2 MHz and planar 400 kHz. From the ultrasonically obtained images it is possible to recognise the geometry of defects and to estimate their approximate dimensions.

Keywords: wind turbine blade, ultrasonic NDT, pulse-echo.

Introduction

Wind power is a promising source of environmentally safe energy. However, in order to prevent the damages and accidents of the construction components of the wind turbine, they should be inspected and monitored periodically. One of the essential components in wind turbines are their blades. Wind turbine blades are multilayered, have variable thickness, have a curved surface, are made from anisotropic material and have a lot of manufacturing nonhomogenities. It is necessary to perform continuous condition monitoring of wind turbine blades and the detailed inspection [1]. Inspection methods based on ultrasound, radiography, thermography, acoustics and optics enable to perform quality control and on site inspection [2].

Ultrasonic methods were not applied yet widely for inspection of wind turbine blades. The propagation characteristics of ultrasonic waves were used to determine material properties throughout the volume of a turbine blade. This technique is especially useful for detection and characterization of surface and subsurface flaws [3-5]. Ultrasonic C-scan imaging has been used for area mapping of the composite delamination or interface disbond due to fatigue in normal field operation conditions of the turbine blade [3]. For ultrasonic NDT of wind turbine blades, several other ultrasonic techniques could be proposed [6, 7].

The drawing of the cross-section of the wind turbine blade sample, used for investigations, is presented in Fig. 1. The multi-layered segment of the wind turbine blade under investigation consists of a skin layer (dye coating with GFRP), glue/foam layer and GFRP foundation layer. The mechanical and acoustic properties of each layer were known in advance.

Scanning of the wind turbine blade, which has a curved surface, is also very complicated task. This task can be partially simplified by the fact that most surfaces are curved in one plane only. The curved scanning of such a sample is performed only in one plane. In another plane scanning is linear as usually. The curved scanning looks simple when the surface curvature shape is known in advance. Nevertheless its implementation requires a precise set-up and continuous monitoring of many parameters. The ultrasonic transducer should be positioned at the known distance strictly perpendicularly to the surface. The perpendicularity should be maintained with a high accuracy, because it affects the amplitudes of the received reflections from the internal structure of the object. The main problem in this task is precise determination of the profile of the sample at each point where measurements should be performed.

The ultrasonic contact pulse-echo immersion testing technique with two types of ultrasonic transducers mounted into a moving water container was used for investigation of the artificial internal defects in the wind turbine blade. The testing of the wind turbine blade was performed using two different ultrasonic transducers: focused and planar.

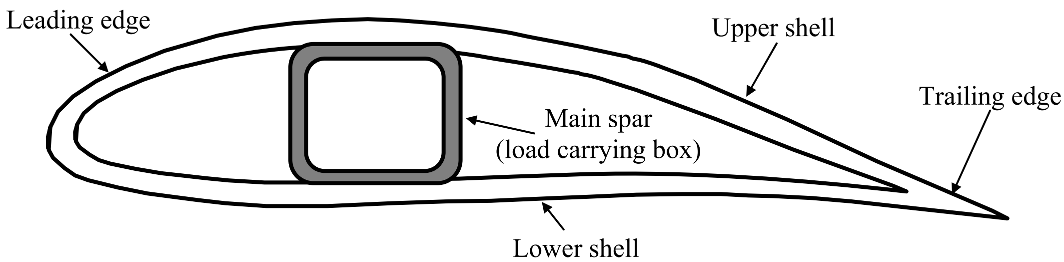

Fig.1. **Typical cross-section of the wind turbine blade**

Experimental set-up

The contact pulse-echo immersion testing (using the moving water container) of the wind turbine blade was performed using two different transducers: focused 2.2 MHz and planar 400 kHz. The pulse-echo experimental set-up using combination of the immersion ultrasonic transducer and the moving water container used for the testing of the wind turbine blade sample is presented in Fig. 2. Oil was used as the coupling liquid between the water container and the surface of the sample.

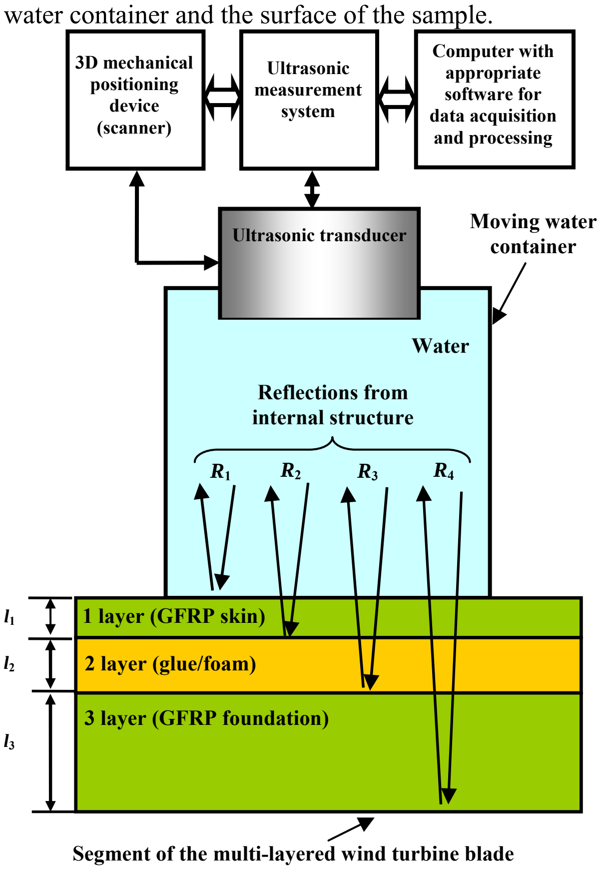

Fig. 2. **The structural diagram of the experimental set-up for a pulse-echo immersion testing of the wind turbine blade**

The focused ultrasonic transducer used for investigation had the central frequency 2.2 MHz, the bandwidth 0.3 f_c, the 22 mm diameter and the focal distance of 50 mm. The ultrasonic transducer was excited by one period burst. The photo of the experimental set-up for the pulse-echo immersion testing of the wind turbine blade using the 2.2 MHz focused transducer is presented in Fig. 3.

The pulse-echo experimental set-up using the planar 400 kHz transducer with the bandwidth 0.4 f_c is presented in Fig. 4. The ultrasonic transducer used for investigation had the diameter of 26 mm. It was alsoexcited by one period burst.

Mechanical positioning of the both types of the transducers and data acquisition were performed using the ultrasonic measurement system developed at the Ultrasound Institute of Kaunas University of Technology. During the alignment of the ultrasonic transducers to the sample surface, it was assumed that the maximum amplitude corresponds to the normal incidence angle to the surface of the sample.

Fig. 3. **The photo of the experimental set-up for testing of the wind turbine blade using 2.2 MHz focused transducer**

Fig. 4.**The photo of the experimental set-up for testing of the wind turbine blade using planar 400 kHz transducer**

Experimental results

Three artificial circular defects on the main spar were tested - with 81 mm, 49 mm and 19 mm diameter. The photo of the inspected artificial circular defect with 81 mm diameter is presented in Fig. 5. The photo of the inspected circular defects with 49 mm and 19 mm diameter is presented in Fig. 6. All these defects were inspected by the contact pulse-echo immersion technique using the moving water container (f=2.2 MHz and f=400 kHz). The defects with 49 mm and 19 mm diameter were also inspected using air-coupled technique using guided Lamb waves (f=290 kHz) [7].

The contact pulse-echo immersion testing (using the moving water container) of the wind turbine blade was performed using a focused transducer (Fig. 3) with the scanning step of 1 mm. In Fig. 7 ultrasonically obtained C-scan image of the internal defect (diameter 81 mm) using the focussed ultrasonic transducer is presented. In this case the shape and diameter of the defect can not be reconstructed because of a natural delamination, which was existing in the test sample.

In Fig. 8 ultrasonic C-scan image of the internal defects (diameters 19 mm and 49 mm) obtained using the focused ultrasonic transducer is presented. In this case the shape and diameter of the bigger defect (49 mm) can be easily reconstructed. The smaller defect (19 mm) can be easily lost between other indications, which show the natural non-homogeneities of the inspected structure.

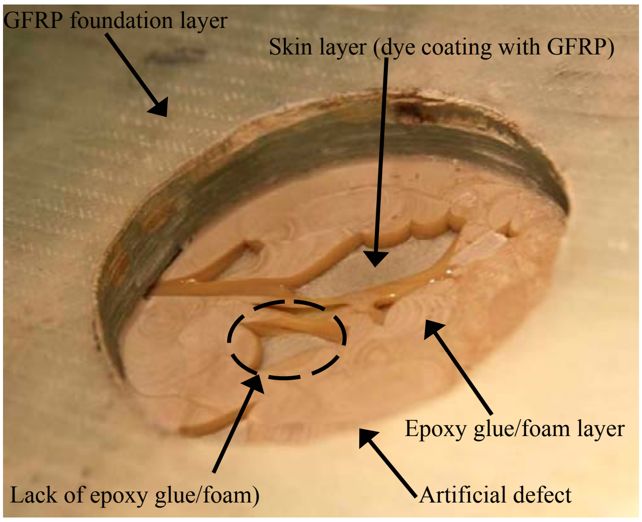

Fig. 5. **Photo of the artificially made defect (diameter 81 mm) on the third layer (GFRP foundation, wall of the load carrying box)**

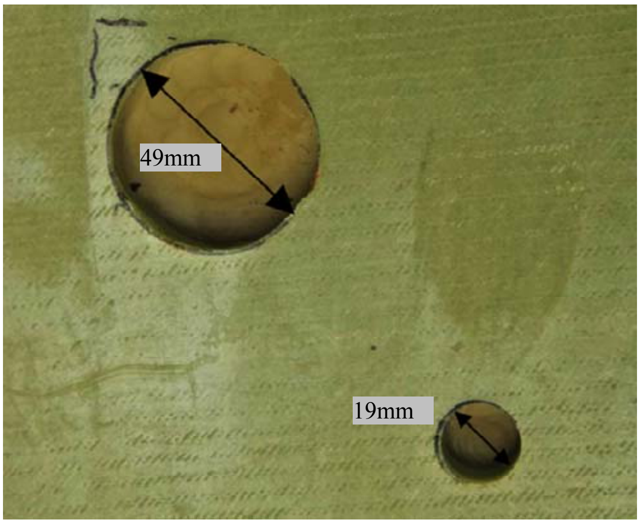

Fig. 6. **Photo of the inspected artificially made defects having circular shape on the main spar**

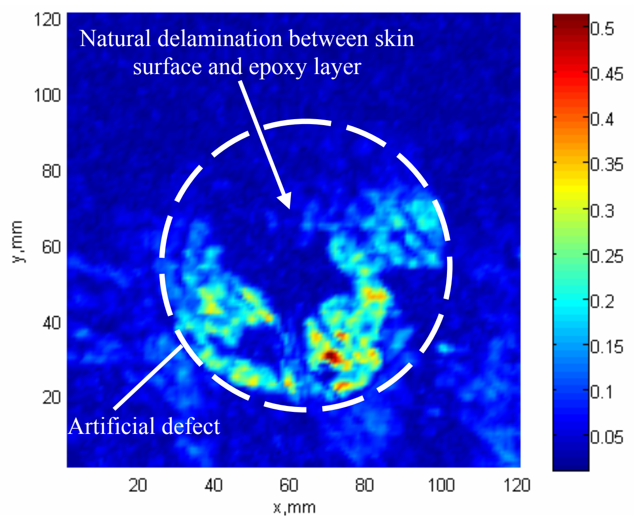

Fig. 7. **Ultrasonically obtained C-scan image using the focused ultrasonic transducer (2.2 MHz) of the artificially made internal defect (diameter 81 mm)**

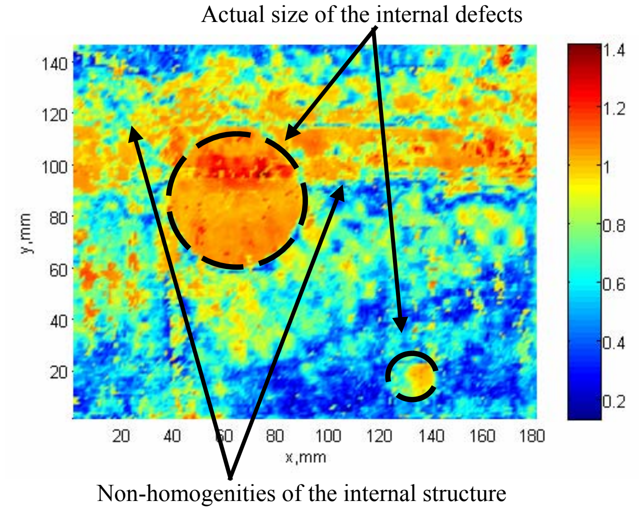

Fig. 8. **C-scan image of the internal defects with diameters 19 mm and 49 mm obtained using the 2.2 MHz focused ultrasonic transducer**

The pulse-echo experimental measurements using the planar 400 kHz transducer were performed (Fig. 4) with the scanning step of 1 mm.

In Fig. 9 a raw C-scan image of the defect with the diameter 81 mm, is presented. In Fig. 10 the corrected C-scan image (the reference signal has been subtracted from the raw C-scan image data, the averaged response of the multilayered medium were taken as the reference signal) of the same defect is presented. In this case the defect can be easier recognized and detected.

In Fig. 11 a raw B-scan image of the 49 mm defect using the low frequency planar ultrasonic transducer is presented. In this case the signal amplitude shows the defected region. In Fig. 12 the C-scan image corrected in the same way as before of the internal defects (diameters 19 mm and 49 mm) is presented. Both defects can be easily recognized and detected using a conventional amplitude detection technique. The ultrasonically obtained corrected C-scan image shows a good contrast, which enables to estimate geometry of the internal defects and their approximate dimensions.

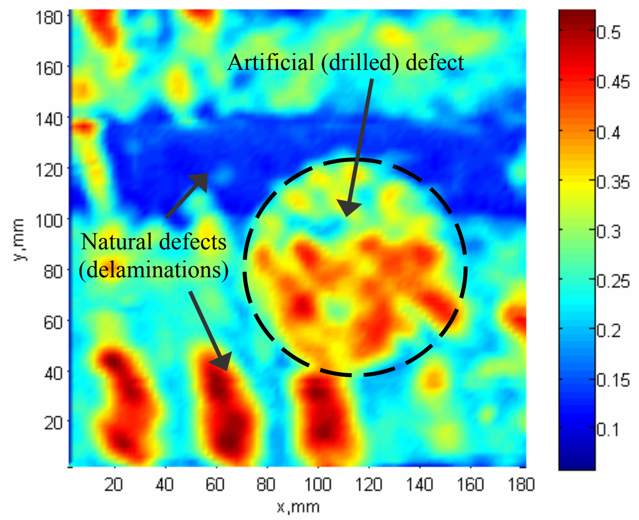

Fig. 9. **C-scan image of the internal artificially made defect 81 mm in diameter obtained using planar 400 kHz transducer**

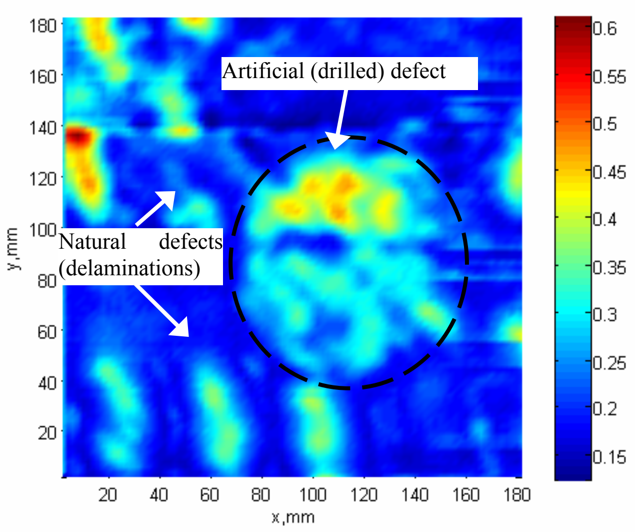

Fig. 10. **The corrected C-scan image of the internal artificially made defect 81 mm in diameter, obtained using the planar 400 kHz transducer**

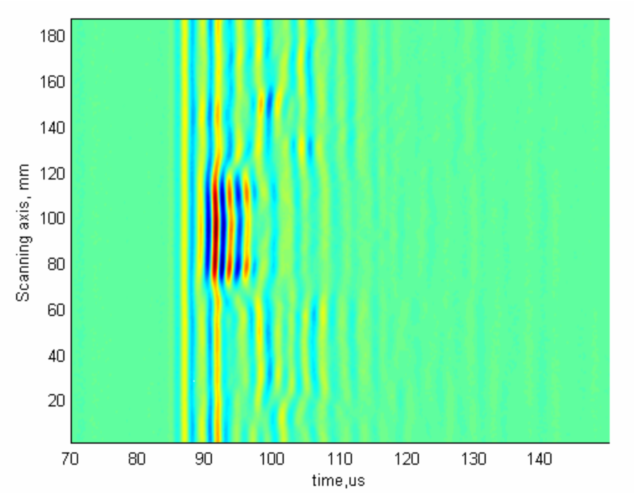

Fig. 11. **B-scan image of the internal artificially made defect having circular shape, with the diameter 49 mm obtained using planar 400 kHz transducer**

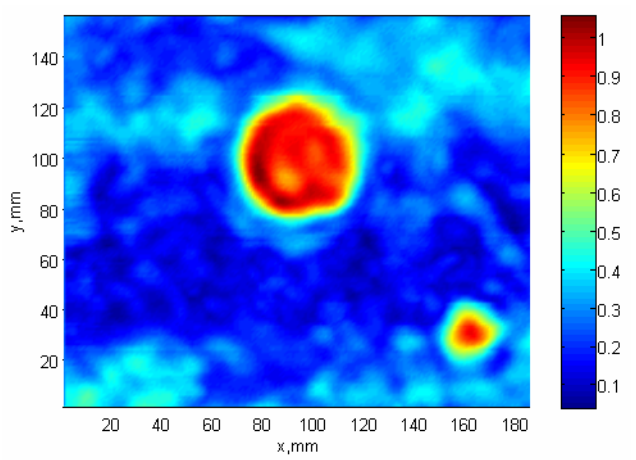

Fig. 12. **The corrected C-scan image of the internal artificially made defects with 19 mm and 49 mm in diameter, obtained using the planar 400 kHz transducer**

Conclusions

For ultrasonic NDT of multilayered wind turbine blades with complicated geometry several different ultrasonic techniques with different transducers have been proposed. Ultrasonic testing techniques proposed and used for investigation of the wind turbine sample are based on a pulse-echo immersion testing using a moving water container. Two different types of ultrasonic transducers were used for investigation of wind turbine blade - focused 2.2 MHz and planar 400 kHz.

The performed measurements show that the contact pulse-echo immersion testing using the moving water container can help to identify the shape and the size of the internal defects better. The higher frequency focused transducer should be used in order to detect delamination type defects near the outer surface of the wind turbine blade. The low frequency planar transducer allows detecting delaminations and thickness variations in deeper layers. However, the best results (detection of different types of defects in different layers) are achieved combining different ultrasonic techniques.

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Vėjo turbinų menčių ultragarsinė neardomoji kontrolė naudojant kontaktinį imersinį aido metodą su judančia vandens talpa

Reziumė

Vėjo jėgainių mentės yra sudėtingas tikrinti objektas – jos yra kreivo paviršiaus, įvairaus storio, daugiasluoksnės, pagamintos iš anizotropinių medžiagų. Kai prieiga yra tik iš vienos objekto pusės, gali būti taikomos dvi ultragarsinės technologijos: tiek nekontaktinė, tiek kontaktinė. Darbe nagrinėtas kontaktinis imersinis aido metodas su judančia vandens talpa ir dviejų tipų ultragarsiniais keitikliais – plokščiuoju ir fokusuotuoju. Tyrimai atlikti esant prieigai tik iš vienos objekto pusės. Buvo ištirti vidinėje sparno dalyje esantys dirbtiniai 19 mm, 49 mm ir 81 mm skersmens defektai. Pasiūlytuoju metodu gauti B ir C tipo vaizdai leido nustatyti vidinių defektų geometrinę formą ir matmenis.

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