Ultrasonic NDT of wind turbine blades using guided waves

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Abstract

In order fully to exploit energy of wind power the construction elements of the wind turbine should be inspected periodically. Ultrasonic air-coupled technique using guided waves has been selected for inspection of wind turbine blades, because only one side access is enough and no contact is needed. Dispersion curves of phase velocities as well as leakage losses versus frequency were calculated using numerical global matrix model.

Taking into account the results of the performed simulations the frequency of the ultrasonic transducers was selected to be 290 kHz due to non-dispersive region of phase velocities. The ultrasonic air-coupled technique using guided waves was used for investigation of the artificial internal defects in the wind turbine blade. These defects (diameter 19 mm and 49 mm) were made on the internal side of the main spar. From the ultrasonically obtained images it is possible to recognise the geometry of defects and to estimate approximate dimensions of the defects.

Keywords: wind turbine blade, guided waves, numerical simulation, ultrasonic NDT

Introduction

Wind power is a fast-growing and very promising source of environmentally safe and renewable energy with a high potential. However, in order to fully exploit energy of wind power the construction elements of wind turbines should be inspected periodically. In order to estimate level of a critical damage at the initial stage before collapsing it is necessary to perform continuous condition monitoring of wind turbine blades and the detailed inspection with elimination of the broken-down components [1].

To keep the wind turbine in operation, implementation of condition monitoring system becomes very important. There are different techniques, methodologies and algorithms developed to monitor the performance of wind turbines. Inspection methods based on ultrasound, radiography, thermography, acoustics and optics enable to perform quality control and on site inspection [2].

One of the essential components in wind turbines are their blades. Wind turbine blades, while in operation, encounter very complex loading sequences, due to the stochastic nature of wind conditions at wind turbines sites. Blade failure is very costly because it can damage other blades, the wind turbine itself and other wind turbines located in neighbourhood. The efficient NDT procedures should extend wind turbine life and reduce failure possibility [1].

Ultrasonic methods were not applied yet very widely for inspection of wind turbine blades. 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]. Three different ultrasonic measurement techniques were used for such investigation: pulse-echo, through transmission and pitch-catch. However, the influence of overlapped reflections, scattering and attenuation of the reflected ultrasonic waves from the multi-layered structure takes place. The scattering effect also has negative impact on the propagation of ultrasonic waves and requires application of lower frequencies. For example, in results presented by Gieske *et al* the contact type testing technique with 400 kHz transducers was used. Such set-up was similar to the guided waves generation in a particular layer of the structure and reception in a neighbour layer of the structure. The authors declare, that the delamination region between mentioned layers gave the shadowing effect. Therefore, such feature helped to detect the internal delamination [3].

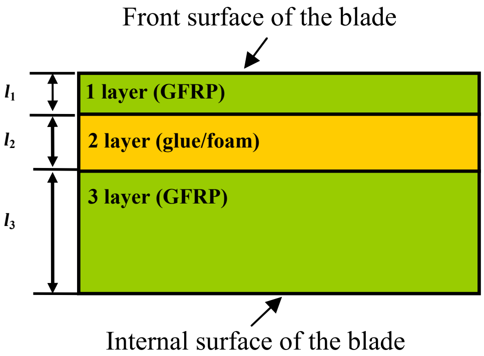
Ultrasonic NDT using guided waves

Application of the guided waves is promising for the detection and sizing of internal defects between individual defects. In the case of guided wave interaction with a structural discontinuity, scattering of guided waves in all directions as well as mode conversion occurs. There are two approaches commonly used for structure health monitoring using guided waves: pulse–echo and pitch–catch [4]. From various characteristics of the received signal, such as the time of flight, amplitude etc., information about the damage in the inspected structure can be obtained. In order to estimate type of the defect, the signal processing algorithms have to be applied [4 - 9].

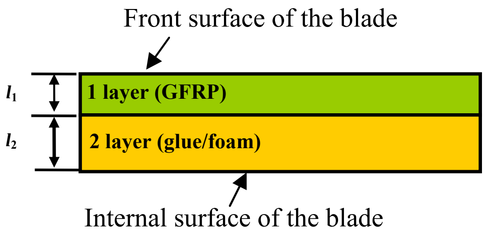
Simulations of phase velocity dispersion curves and leakage losses

For effective exploitation of the guided waves it is necessary to select frequency, therefore the global matrix numerical model has been used for calculation of the dispersion group and phase velocities curves [7-10]. Leakage losses versus the frequency were taken into account also. During simulation the scattering losses inside the GFRP (glass fibre-reinforced plastics) layers have been neglected due to short propagation distance of the guided waves inside the segment of the blade (approximately 40 mm) and also low operating frequencies of the air-coupled ultrasonic set-up. Anisotropy was neglected also.

The drawings of the structures, for which phase and group velocity dispersion curves were calculated, are presented in Fig. 1. The structure, selected for simulations was similar to the real structure of the inspected wind turbine blade sample. In Fig. 1, a the defect free structure is presented, in Fig. 1, b – defected region (without the third layer, in order to simulate delamination type defect due to bad adhesion of glue/foam) is presented. Parameters of the layers used for simulations are listed in Table 1. The lateral dimensions of the structure have been assumed to be infinite.



a



b

Fig. 1. **The simulated multi-layered structure of the wind turbine blade segment a - defect free region, b –defective region**

Table 1. Parameters of the materials

	Material	l, mm	ρ, kg/m^3	c_l, m/s	c_s, m/s
1 layer	GFRP	3	1870	2743	1917
2 layer	Glue/foam	5	1100	2400	1200
3 layer	GFRP	12	1870	2743	1917

The calculated phase velocity dispersive curves as well as leakage losses versus frequency for defected and defect free regions are presented in Fig. 2 - 5. From the presented results it can be seen that for ultrasonic NDT of wind turbine blades the 290 kHz transducers may be used due to low leakage losses and less dispersive region.

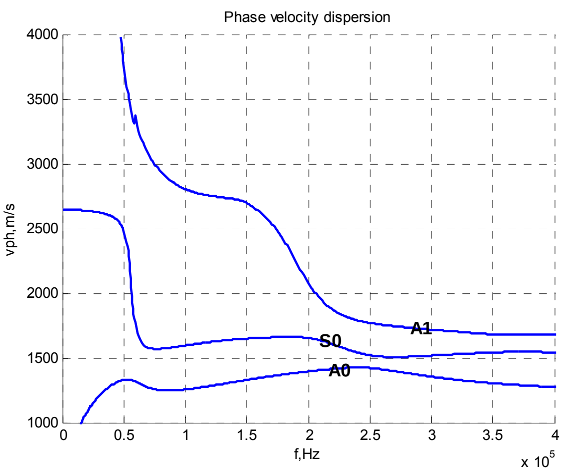


Fig.2. **Phase velocity dispersion curves in the defect free structure**

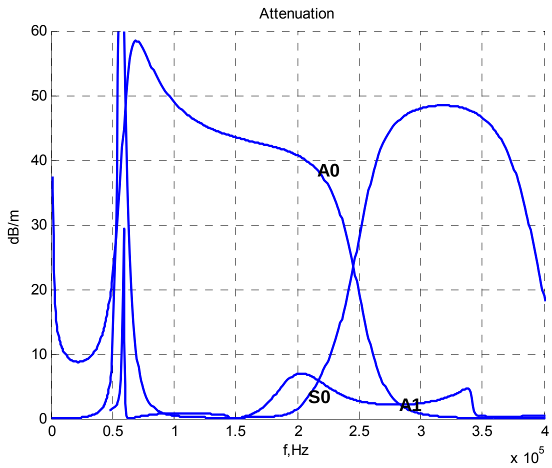


Fig. 3. **Leakage losses versus frequency in thedefect free structure**

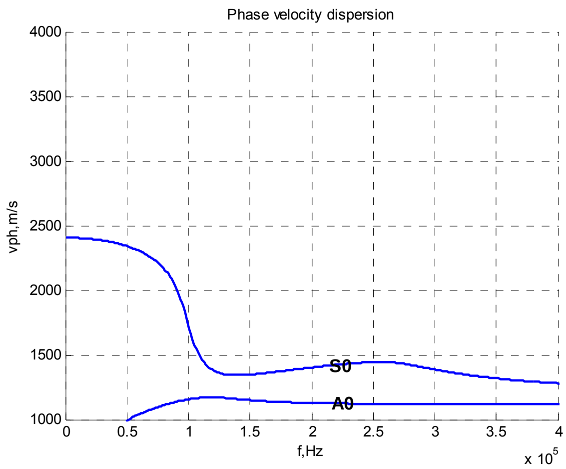


Fig.4. **Phase velocity dispersion curves in thedefected structure**

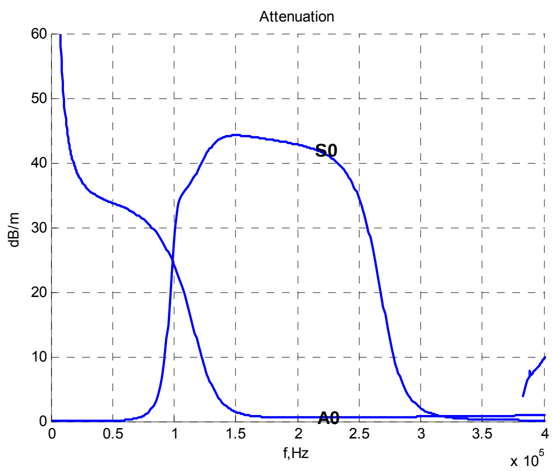


Fig.5. **Leakage losses versus frequency in the defected structure**

Experimental investigations

The measurements were performed using the air-coupled ultrasonic measurement system, which has been developed at Ultrasound Institute of Kaunas University of Technology. The photo of the experimental set-up is presented in Fig. 6.

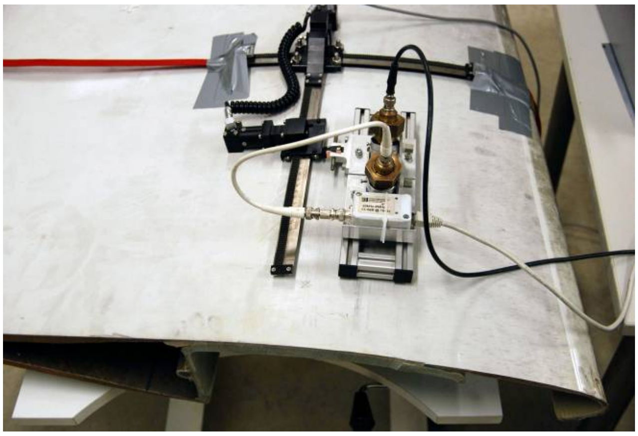


Fig.6. **Photo of the air-coupled experimental set-up for wind turbine blade NDT**

The pair of air-coupled transducers has been used for non-contact scanning of the wind turbine blade sample. Positioning of the ultrasonic transducers has been performed by a precise mechanical scanning unit. Only one-side access to the sample surface was used. The structural diagram of the used air- coupled ultrasonic technique for NDT inspection of the wind turbine sample is presented in Fig. 7.

The frequency of the ultrasonic transducers f=290 kHz has been selected taking into account the simulation results obtained using the global matrix calculation technique. The transducers were mounted into pitch-catch configuration for generation and reception of guided ultrasonic waves. The transmitter was driven by the 8 periods and 750 V amplitude radio pulse. The total gain of the measurement system was 77 dB. Averaging of the 4 received signals was performed. The measurements were performed with the scanning step of 2 mm.

The cross-section of the inspected wind turbine blade sample is presented in Fig. 8. The photo of the inspected artificial circular defects with 49 mm and 19 mm diameter is presented in Fig. 9. In Fig.10 the A-scans obtained over defected (1) and defect free (2) regions are presented. As can be seen from the waveforms, the signal amplitude over the defected region is considerably smaller. In Fig.11 the B-scan image of the 19 mm defect is presented. Lack of the leaky wave signal corresponds to the defected region. In Fig.12 the C-scan image of the 49 mm and 19 mm defects is presented. Both defects can be easily recognised and detected using a conventional amplitude detection technique. The ultrasonically obtained C-scan image shows a good contrast, which enables to estimate geometry of the defects and their approximate dimensions.

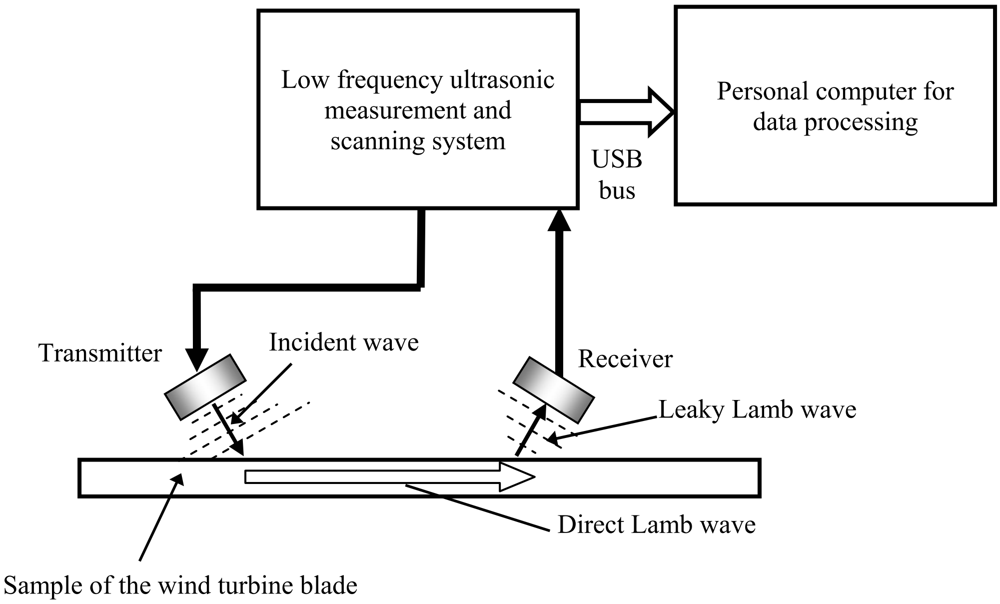


Fig.7. **The air-coupled ultrasonic technique used for NDT inspection of the wind turbine blade sample**

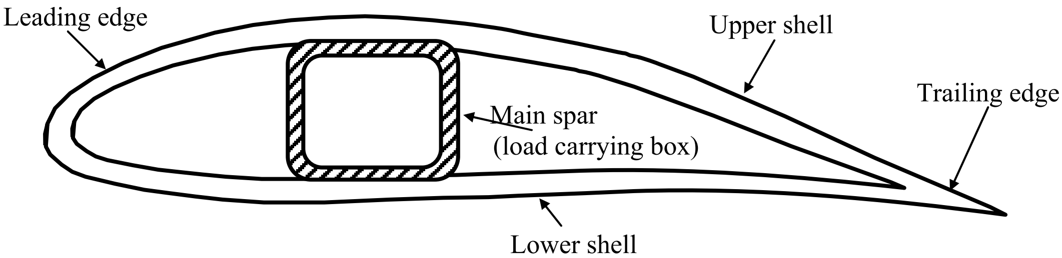


Fig.8. **Cross-section of the wind turbine blade**

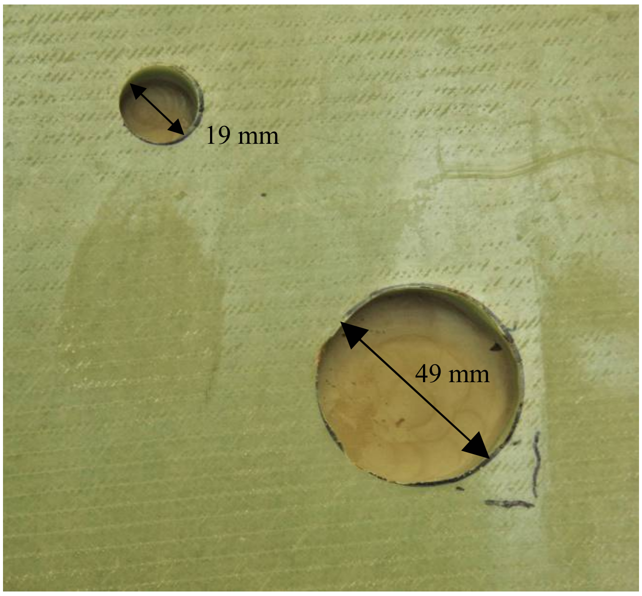


Fig.9. **Photo of the inspected artificially made defects having circular shape on the main spar**

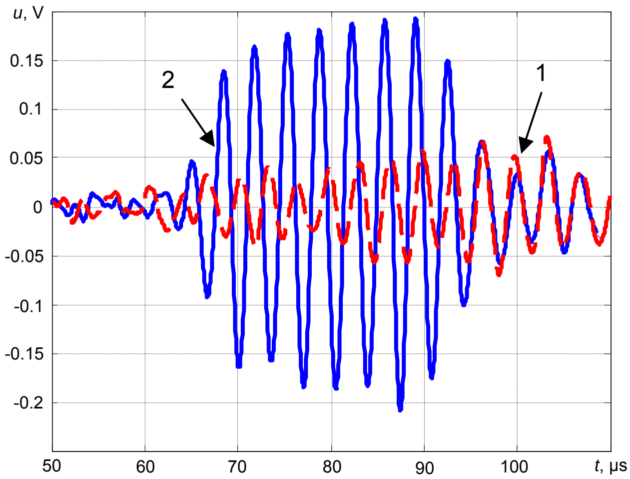


Fig.10. **The A-scan image obtained over defected (1) and defect free regions (2)**

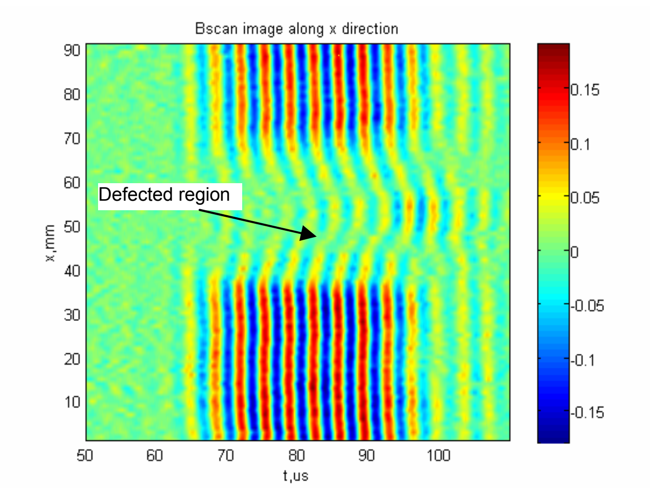


Fig.11. **The B-scan image of the wind turbine sample**

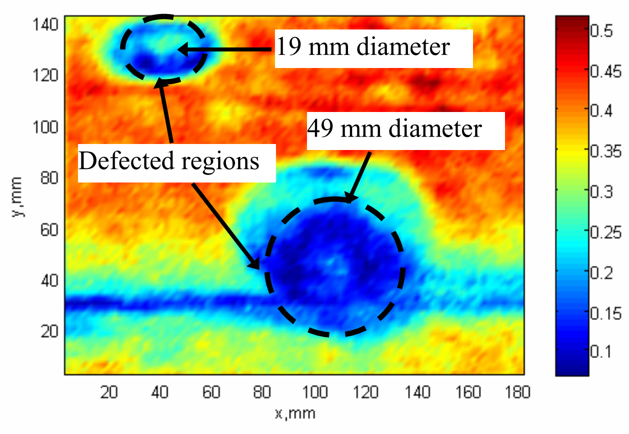


Fig.12. **C-scan image of the wind turbine sample**

Additionally, the darker line at y=30 mm indicates, that besides the known defects in the sample there are unknown defects or variayions of material properties, which have to be inspected in the future.

Conclusions

For ultrasonic NDT of wind turbine blades ultrasonic technique using the air-coupled generation of guided waves has been selected due to only one side access and non-contact experimental set-up.

Simulations of group and phase velocity dispersion curves as well as leakage losses versus frequency for defected and defect free regions were performed using thenumerical global matrix model. From the simulation results it can be seen that for ultrasonic NDT investigations of wind turbine blades fundamental A_0 mode should be used due to low leakage losses and less dispersive region at the frequencies higher than 290 kHz.

The first measurements show that the proposed air-coupled ultrasonic technique, using Lamb waves allows finding defects in wind turbine blades. The ultrasonically obtained images (A-scan, B-scan, C-scan) show defects geometry and approximate dimensions.

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Vėjo turbinų menčių ultragarsinė neardomoji kontrolė naudojant nukreiptąsias bangas

Reziumė

Vėjo energija yra vienas iš perspektyvių energijos šaltinių. Tačiau, kad vėjo energija būtų panaudojama visiškai ir saugiai, vėjo jėgainės konstrukciniai elementai turi būti periodiškai tikrinami.

Vėjo jėgainių menčių neardomajai kontrolei pasirinktas nekontaktinis (per oro tarpą) ultragarsinis matavimo naudojant nukreiptąsias Lembo bangas metodas. Tyrimai atliekami esant prieigai tik iš vienos objekto pusės. Atsižvelgiant į skaitmeninio modeliavimo rezultatus, gautus globaliosios matricos metodu, buvo pasirinktas ultragarsinių keitiklių darbo dažnis f=290 kHz mažai disperguojančiose fazinio ir grupinio greičio srityse. Vėjo jėgainių sparnams tirti pasirinkta A_0 Lembo bangų moda. Buvo ištirti vidinėje sparno dalyje esantys dirbtiniai 19 mm ir 49 mm skersmens defektai. Pasiūlytuoju metodu gauti A, B ir C vaizdai leido nustatyti vidinių defektų geometrinę formą ir matmenis.

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