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METHODOLOGY OF THE ACOUSTIC EXPERIMENT FOR STUDYING THE AERODYNAMIC NOISE OF WIND TURBINE BLADE SEGMENTS

Purpose. This work focuses on developing and implementing the methodology for studying the aerodynamic noise generated by the rotor of a wind turbine. The acoustic characteristics of this noise are analyzed using a blade segment with NACA0012 airfoil. The study addresses the ongoing challenge of reducing wind turbine noise in renewable energy systems.

Methodology. The aerodynamic noise of a wind turbine blade segment was experimentally investigated under laboratory conditions in an anechoic chamber. The measurement procedure complies with the national standard DSTU GOST ISO 5725-1:2005.

Findings. The paper provides a brief overview of existing approaches to studying aerodynamic noise from wind turbines and presents a custom-designed experimental setup for studying acoustic noise characteristics of blade segments in an anechoic chamber. A method is proposed for analyzing both the acoustic signals of interest and the background noise components. Sound pressure levels were measured, and spectral characteristics of the noise generated by the blade segment with NACA0012 airfoil were analyzed in the presence of background noise. The method demonstrated effective operability for laboratory-based acoustic studies.

Originality. The proposed method represents an original approach that differs from the traditional ones, in which test sections are integrated into an anechoic acoustic environment. Unlike conventional methods that assume a stationary model position and reversed flow conditions, this setup simulates the rotational motion of the blade airfoil. This enables a more realistic replication of operational rotor conditions and yields experimental data that better reflect actual aerodynamic noise behavior.

Practical value. The developed methodology and experimental setup are applicable to parametric studies of various blade profiles to identify noise-reducing blade modifications. The results are also valuable for validating numerical models of aerodynamic noise prediction for turbine blades.

Keywords: *renewable energy, wind turbines, aerodynamic noise, acoustic experiment, noise spectra*

Introduction. The policy of sustainable development and decarbonization of the energy sector encourages the advancement of alternative energy technologies, particularly through the increased deployment of wind turbines. According to forecasts, by 2050 global wind generation will reach 18,300 TWh, with an average annual growth rate of 8 % [1], and wind power plants will provide up to 31 % of global electricity production, positioning wind energy as one of the key sources of renewable power. However, the operation of wind turbines is associated with the problem of aerodynamic noise, which occurs due to the interaction of turbine blades with the air flow. This noise negatively affects the environment and creates discomfort for people living or working near wind turbines [2]. In most countries where wind energy is actively developing, the level of aerodynamic noise from wind turbines is limited to a value of up to 55 dB [3]. Therefore, when designing wind power plants, it is important to predict the noise level from different modifications of wind turbines and to find methods for reducing the noise pollution.

The sources of wind turbine noise can be categorized as either mechanical or aerodynamic. The impact of mechanical noise can be mitigated through precise component manufacturing, the use of vibration-absorbing materials and the efficiency of maintenance. In contrast, aerodynamic noise arises from the interaction of the airflow with the turbine blades, in particular through the formation and development of vortex structures in the boundary layer and their subsequent interaction with the blade elements. These vortices induce acoustic vibrations, which are subsequently radiated into the surrounding environment.

Mitigating the influence of aerodynamic factors on noise generation requires an in-depth investigation of acoustic processes using both theoretical and experimental methods. The correctness and reliability of such studies largely depend on the justified choice of the appropriate methodology and the conditions for its implementation.

This study briefly analyzes the problem of noise generation by wind turbine blades and proposes a novel methodology for conducting acoustic experiments, which allows studying the influence of vortex structures and blade profile parameters on the characteristics of aerodynamic noise.

Literature review. Currently, there is a fairly large number of articles devoted to modeling the processes of generation and propagation of aerodynamic noise from wind turbines. The survey of key works in this area is presented, notably, in [4, 5]. The complexity of modeling arises from the multifactorial nature of the phenomenon, which encompasses a wide range of physical mechanisms responsible for noise generation. The main ones are related to the behavior of the boundary layer, transition to turbulence, the formation of vortex structures, and their further development. Table summarizes the main aerodynamic noise generation mechanisms according to [6, 7].

Therefore, it can be concluded that the main mechanisms of aerodynamic noise generation are: the development of the boundary layer, the appearance and evolution of turbulence around the streamlined surface, and the interaction of turbulent structures with the trailing edge of the blade.

Aerodynamic noise can generally be classified into two main categories: broadband noise and tonal noise, each exhibiting distinct characteristics. Broadband noise spans a wide frequency range without prominent peaks and is typically perceived as a low-frequency hum. It is primarily generated by stochastic turbulent processes. Tonal noise, by contrast, contains distinct frequency components (tones) and is characterized by narrowband spectral peaks. It often resembles high-pitched sounds such as buzzing or whistling and is generally considered more disturbing to the human ear.

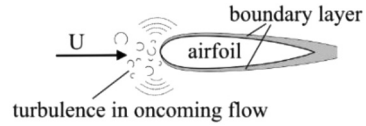
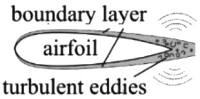
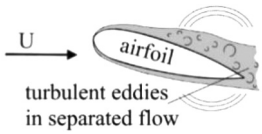
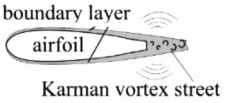
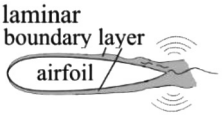
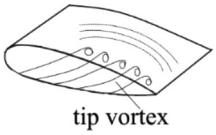
The modern approach to the study of wind turbine aerodynamics is based primarily on numerical modeling, which has become the main tool in this field. Numerical methods provide the ability to conduct large-scale studies with acceptable accuracy and optimal resource consumption [8]. The complexity of such models varies from semi-empirical models [9], and models based on simplified theories and meshless approaches [10, 11], to computational fluid dynamics (CFD) approaches based on the Navier-Stokes equations [12, 13]. Recently, machine learning-based approaches have been developed for acoustic optimization of wind turbines [14]. At the same time, the reliability of such computations directly depends on their validation based on experimental or field data. Therefore, experimental studies remain an independent and powerful tool that allows for the identification of complex physical mechanisms that are inaccessible to full-fledged numerical description. In particular, when studying the mechanisms of aerodynamic noise, the experiment is a key source of reliable information.

Among the main approaches to reducing aerodynamic noise from wind turbine blades, passive methods currently predominate, including blade profile optimization, trailing edge modifications, and the use of specialized inserts or coatings [15]. The evaluation of these noise mitigation strategies is not possible without experimental investigations, which are essential for validating and improving noise reduction techniques.

Field measurements of noise emitted by small wind turbines have been conducted in several studies. For instance, [16] reports on a three-bladed wind turbine installed on the roof of an insulated high-rise building,

Table

Mechanisms of aerodynamic noise generation

No	Scheme	Description
1		The interaction of turbulent vortices in the oncoming airflow with the leading edge of the blade generates broadband low-frequency noise (up to 1,000 Hz). This type of noise strongly depends on the intensity and scale of atmospheric turbulence
2		Noise resulting from the interaction of the turbulent boundary layer with the sharp trailing edge of the blade. This noise is broadband in nature with a peak frequency in the range of 500–1,500 Hz and is the dominant source of noise in wind turbines
3		At certain angles of attack, the phenomenon of flow separation from the blade surface may occur, the flow becomes significantly unsteady, which causes broadband sound radiation
4		When the blade profile features a blunt trailing edge, a von Kármán vortex street may form downstream, producing tonal noise. This tonal component is dependent on the trailing edge geometry and the Reynolds number
5		At low Reynolds numbers, the boundary layer may remain laminar across the blade surface. However, the instability of this laminar layer can resonate with trailing edge noise, resulting in significant tonal noise emissions. This effect is especially pronounced in small wind turbines
6		The tip vortex is generated by the pressure difference between the pressure and suction sides of the blade. Its interaction with the trailing edge produces high-frequency broadband aerodynamic noise. Since the frequency of this noise falls within the range of human hearing, it is a major contributor to perceived noise discomfort caused by wind turbines

where sound power was measured for different blade profile configurations. Field studies of low-power (1 kW) turbine noise were also conducted in [17] to compare turbine noise with environmental noise.

A significant challenge in field measurements is isolating turbine-generated noise from other environmental sound sources, which can result in inaccuracies in estimating aerodynamic noise levels. Moreover, weather conditions such as wind speed, humidity, and air temperature can affect measurement accuracy, posing methodological challenges in controlling and accounting for these variables.

Most researchers studying aerodynamic noise from blades use wind tunnels.

For example, [18] experimentally examined the noise generated by blades with trailing edge cracks using a NACA 0018 airfoil at various angles of attack and flow velocities. Acoustic measurements were performed with microphones positioned around the airfoil. The obtained data were analyzed to identify a correlation between the noise characteristics and the presence or size of cracks on the trailing edge of the blade.

The experimental technique for acoustic measurements of wind turbine aerodynamic noise in the far field using a microphone setup is described in detail in [19].

The methodology and technique of the aerodynamic experiment for the study and measurement of airfoil noise in the wind tunnel of the Institute of Aerodynamics and Gas Dynamics of the University of Stuttgart are discussed in [20]. The authors conducted experimental studies on scaled models of wind turbines in a wind tunnel, using a microphone array to localize and evaluate noise sources. The results showed that the use of a microphone array is an effective method when studying the noise spectra of wind turbine blades.

A detailed investigation of tonal noise generated by a modified NACA 0012 airfoil was carried out in an open-type wind tunnel in [21]. The study demonstrated that the application of porous inserts can effectively reduce the tonal noise level.

It is important to note that acoustic experiments conducted in wind tunnels are technically demanding and require specialized laboratory equipment to minimize the influence of reflected sound waves. This often involves the use of specialized wind tunnels with test sections situated within anechoic acoustic environments. The methodology for performing such experiments is comprehensively described in [22].

In summary, the methodology for laboratory studies of aerodynamic noise from wind turbine blades is generally well developed; however, its accuracy and applicability still require further refinement. Specifically, the measurement results depend to a large extent on the configuration of the microphone setup, namely on their location and resolution. These parameters affect the ability to accurately localize noise sources, especially on blades that rotate rapidly in real conditions. The acoustic characteristics of the noise depend on the Reynolds number, which determines the flow regime around the blade, as well as on the conditions of a particular experiment, such as the flow velocity and the geometry of the model. Also, one of the key problems is to extract the aerodynamic noise of the blades from the background noise of the wind tunnel and the influence of vibrations of the stand, which can distort the results. These limitations emphasize the need to develop the methodology of acoustic experiments, in particular to find effective solutions to reduce the tonal noise that is characteristic of the operation of wind turbine blades.

It is also important to highlight that wind tunnel experiments are typically conducted based on the principle of stationary blowing, where the blade model (or its segment) remains fixed while airflow is used to simulate blade movement. This approach differs from real operating conditions, in which the blades rotate within the atmosphere, complicating the direct application of experimental results to full-scale, real-world structures.

Purpose. This work aims to develop and refine a methodology for investigating aerodynamic noise generated by wind turbines, with a focus on analyzing the acoustic characteristics of noise produced by a blade segment featuring a NACA 0012 airfoil. Although this symmetrical profile is not commonly employed in practical wind turbines due to its aerodynamic properties, it was selected as a test object because of its simple geometry and the abundance of available reference data.

The proposed methodology is based on experiments conducted within an anechoic chamber. Unlike the traditional methods that typically use wind tunnels with stationary blowing of the model, this approach employs a rotating test model of a wind rotor segment. This setup allows for significant simplification of the experimental arrangement while maintaining accurate modeling of physical processes, particularly the aerodynamic noise generated by blades under conditions closely resembling real operational environments.

Methods. To study the spectral characteristics of wind turbine blade noise, a special experimental setup was developed at the National Technical University "Dnipro Polytechnic" (Dnipro, Ukraine). To minimize the influence of external noise sources and sound waves reflected from the walls, the setup was placed in an anechoic chamber with dimensions of 3.8 × 3.8 × 3.2 m, the walls of which were covered with sound-absorbing materials.

The experimental setup consisted of a model of an aerodynamic blade segment, a mechanical part and a measuring unit. A schematic view of the setup is presented in Fig. 1.

The mechanical part of the setup consisted of an electric drive that rotated a rod with an experimental model attached to its end. The model was placed be-

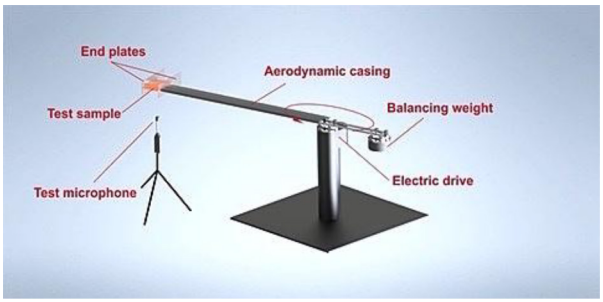


Fig. 1. Scheme of an experimental setup for studying the aerodynamic noise of a wind turbine blade segment

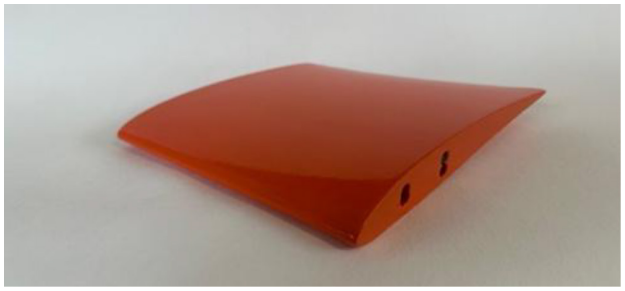


Fig. 2. Blade test segment model with a variable-span chord

tween two end plates to prevent the formation of end vortices due to the effect of air flow at the ends. A balancing weight was attached to the opposite end of the rod.

The measuring unit consisted of a sound level meter SV 971A1 of IEC 61672-1:2013 class, which allows measuring noise in the frequency range of 5 Hz–20 kHz. The device is equipped with a pre-polarized condenser microphone ACO SV 7152 1⁄2" with a nominal sensitivity of 32 mV/Pa. During the experiments, the sound level meter was placed stationary. The sensor was located in a plane parallel to the plane of the model's movement trajectory at a specified distance from the test sample. The results were processed using specialized software SVAN PC++.

By 3D printing, models of test segments of the blade were made: a straight segment with NACA0012 profile with a chord length of 10 cm and a segment with a variable-span chord with an average length of 21.5 cm (Fig. 2). The dimensions of the test segment models are chosen to avoid the need for scaling and to match the parameters of the middle and end parts of the blades of small and medium wind turbines.

Fig. 3 shows a working version of mounting the blade segment model on a measuring stand with end plates.

A series of experiments was conducted to verify the operability of the methodology and ensure the repeatability and convergence of the obtained experimental data using the provisions of DSTU GOST ISO 5725-1:2005 by the example of a segment with NACA0012 profile with a chord length of 10 cm.

Fig. 3. The blade test segment model mounted on a measuring stand

During experimental studies, the microphone of the sound level meter was placed at a distance of 0.1 m from the level of the trailing edge of the segment. The speed of rotation of the rod provided the linear speed of movement of the test segment equal to $v = 24$ m/s, the angle of attack was 0°. Aerodynamic noise measurements within one experiment were carried out for 5–10 seconds. The duration and position along the time axis of the observation interval corresponded to a separate passage of the model over the microphone. The duration of the observation interval was chosen in accordance with the distance traveled by the blade segment, which was taken to be equal to the length of the profile relative to the moment of passage of the trailing edge of the test segment over the microphone.

An important task is to extract the necessary frequency components of noise, to analyze the influence of a specific source. For this, spectral analysis is used based on the Fast Fourier Transform (FFT) algorithm, with a resolution of 12 Hz. Let $x(t)$ be the output signal, $n(t)$ – the background noise, and $s(t)$ – the useful signal that needs to be extracted. Then, the relationship can be expressed as follows

$$x(t) = s(t) + n(t)\ x(t) = s(t) + n(t)\,,$$

where t is time. According to the Fast Fourier Transform algorithm, after transformation, the signals are represented in the frequency domain as

$$X(f) = S(f) + N(f),$$

where $X(f)$, $S(f)$, $N(f)$ are the amplitude spectra of the corresponding signals. Estimation of the spectrum of the useful signal after noise removal is

$$\tilde{S}(f) = X(f) - \alpha \cdot N(f),$$

where α is a coefficient that determines the level of noise reduction (usually $1 \le \alpha \le 2$). If the spectrum after subtraction has negative values, the following correction is applied

$$\tilde{S}(f) = \max\left[\left|X(f)\right| - \alpha \cdot \left|N(f)\right|, 0\right] \cdot e^{i\angle X(f)},$$

where $\angle X(f)$ is the phase of the original signal. After this, the inverse Fourier transform is performed

$$s(t) = F^{-1}\left[\tilde{S}(f)\right] = \int_{-\infty}^{\infty} \tilde{S}(f) \cdot e^{-2\pi f t} df.$$

Power spectral density (PSD) p obtained from the measurements was converted into sound pressure level (SPL) in dB.

$$SPL = 20 \cdot \log_{10}\left(\frac{p}{p_0}\right),$$

where p_0 is the reference value of the sound pressure amplitude is 20 μPa.

The convergence of the experimental results was established based on the assessment of the average relative deviation of the sound pressure level D_n by analyzing the change in the value of the averaged spectrum over a subset of measurements. The convergence of experimental studies was assessed by averaging the results over 20 observation intervals. Fig. 4 shows the change in , depending on the number of observation intervals over which averaging was performed.

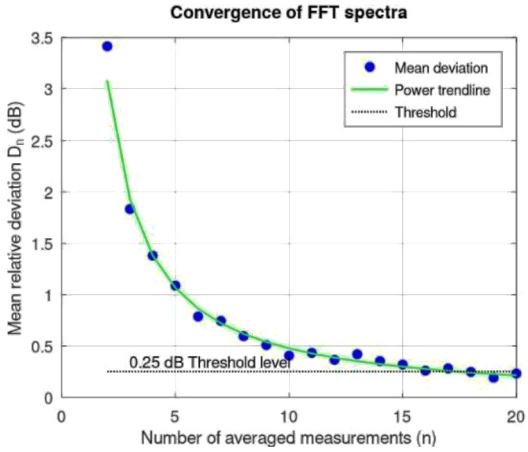


Fig. 4. Results of convergence studies (markers – experiment; line – average value)

As can be seen from the data in Fig. 4, after averaging over 16 measurements, the average deviation value becomes less than the level of 0.25 dB, which was taken as the threshold value. And the signal changes between neighboring points $\Delta D_n = D_n - D_{n-1}$ are less than 0.05 dB, which can be considered quite acceptable. This approach to analyzing the convergence of experimental data results complies with the standards for measurements in acoustics and vibration testing ISO 3745:2012, IEC 61260-1:2014. According to these standards, a deviation of less than 1 dB is acceptable for laboratory conditions. Therefore, in the future, in order to reduce the influence of random fluctuations and to increase the reliability of the data, the results of the noise spectra are presented as averaged values over 20 observation intervals.

To reduce the influence of the noise of the electric drive on the measurement results, a soundproofing screen was installed between the drive and the sound level meter. Fig. 5 presents the FFT spectra of the background noise in the "quiet" anechoic chamber and the noise of the operating drive of the experimental stand.

As shown in Fig. 5, the frequency distribution of background noise in the chamber exhibits no distinct peaks; however, the sound pressure level increases in the low-frequency range, reaching 35 dB at 100 Hz. In contrast, the experimental results indicate that the noise level of the electric drive exceeds the background noise in the frequency range of 800–2,000 Hz, with a maximum peak of 25 dB. The use of a soundproof screen between the drive and the microphone effectively minimized the influence of the drive noise, which, on average, exceeded the background level by less than 5 dB, with a brief peak of 20 dB.

A repeatability study was carried out using the NACA0012 airfoil with a chord length of 10 cm, based on data from three experimental series conducted on different dates with intervals of 52 and 2 days, respectively (Fig. 6).

The results presented in Fig. 6 demonstrate both qualitative similarity in the spectral shape and quantitative stability. All three series exhibit a consistent spectral profile: a decline from low to high frequencies with a pronounced rise in the mid-frequency range (~1–2 kHz). The main peaks and dips appear in all series, with only minor amplitude variations (approximately 1–3 dB). The amplitude characteristics remain stable across all measurements. The maximum deviation observed in the low-frequency region for Series 1 may be attributed to changes in environmental conditions such as temperature, humidity, or background noise. Overall, the repeatability of the experimental results is confirmed.

Results. The test results confirm the functionality and viability of the developed method for measuring acoustic noise generated by wind turbine blade segments. This method was applied to investigate tonal noise produced by a blade segment featuring a NACA 0012 airfoil profile with an average chord length of 21.5 cm.

A critical step in the acoustic measurement process is isolating the noise generated by the test object from the background noise of the experimental setup. To achieve this, the experiments were conducted in two phases. First, the background noise in the chamber was recorded without the model installed. Then, acoustic measurements were taken with the model in place. The results of background noise filtering, starting from 100 Hz, are presented in Fig. 7.

The signal (blue curve) clearly shows local increases in the noise level in the range of ~500–1,200 Hz, which is due to the presence of tonal components. The background noise is much lower, on average by about 10 dB, and more uniform. It can be noted that the influence of the background noise of the experimental stand on the measurement results is generally relatively small and does not have a qualitative impact. Information in the

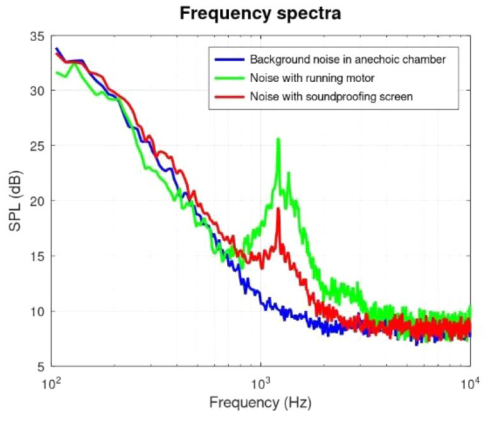


Fig. 5. Assessment of the sound pressure level of various noise sources

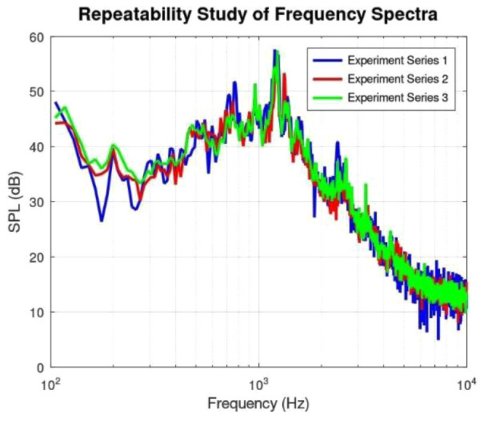


Fig. 6. Results of repeatability tests

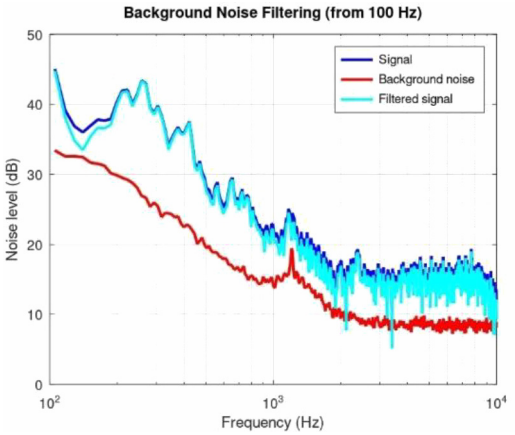


Fig. 7. Result of filtering averaged FFTs noise spectra of a test segment with NACA 0012 profile with an average chord length of 21.5 cm, moving at a speed of 10 m/s with an installation angle of 5°

tonal noise range is determined, which allows further analysis of the source characteristics.

Fig. 8 presents a spectrogram of the aerodynamic noise recorded over a 2.6-second interval using a sound level meter.

The spectrograms shown in Fig. 8 display clearly defined peaks in the sound pressure level (SPL) distribution at regular time intervals. These peaks correspond to the rotation frequency of the rod and, consequently, to the frequency at which the blade segment passes the observation point (microphone). Based on this information, the appropriate time points were identified to define the observation interval.

Fig. 9 presents the averaged noise spectra obtained via fast Fourier transform (FFT) for the test segment at linear velocities of 10, 12.5, 15, 17.5, and 20 m/s.

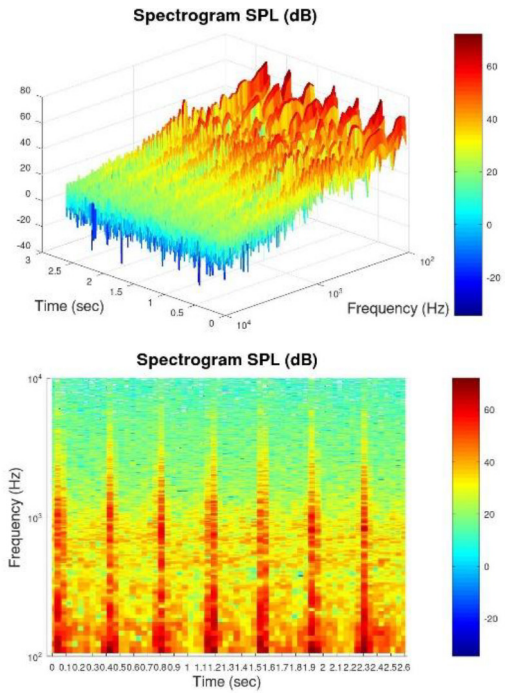


Fig. 8. Spectrogram of aerodynamic noise of a test segment with NACA 0012 profile moving at a speed of 10 m/s with an installation angle of 5°

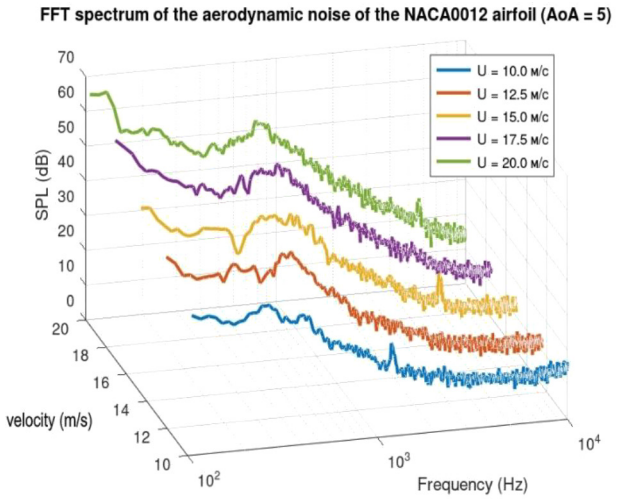


Fig. 9. Averaged FFTs noise spectra of the test segment with NACA 0012 profile for different speeds with an installation angle of 5°

The averaged FFT noise spectra for all test cases exhibit characteristic tonal noise peaks, with maximum values exceeding the broadband noise level by 5–10 dB. The frequency of these tonal peaks depends on the velocity of the incoming flow; the peaks occur in the low-frequency range and shift upward with increasing speed – from approximately 250 Hz at 10 m/s to 800–900 Hz at 20 m/s. Additionally, in the high-frequency range, aerodynamic noise consistently decreases with increasing frequency for all tested velocities.

For practical evaluation and comparison of the overall aerodynamic noise levels, it is useful to employ the equivalent continuous sound level (*Leq*) – a metric representing the constant noise level that would convey the same acoustic energy as the time-varying noise over a specified duration.

$$Leq = 10\lg\left(\frac{1}{T}\int_0^T 10^{L(t)/10}\,dt\right),$$

where T is the measurement duration; $L(t)$ is the current noise level in dB.

Fig. 10 presents the dependence of the equivalent noise level of the test blade segment under study on the oncoming flow velocity.

The presented data shows that the equivalent noise level in the conducted studies increases from ~88 to 100 dB with increasing blade rotation speed.

Fig. 10 also presents the equivalent noise levels generated by the experimental setup during the rotation of the rod with a balancing weight (without the test segment), as well as the equivalent level of background noise recorded in the chamber when the setup was not operating. The equivalent noise level during rod rotation without the test segment was found to be 20 dB lower than the level of the main signal. This indicates a minimal influence of the experimental setup's noise on the measurement results.

Conclusions. An original experimental method for modeling the aerodynamic noise of a wind turbine blade segment under laboratory conditions in an anechoic chamber has been developed and tested. In contrast to the traditional wind tunnel approaches, the implementation

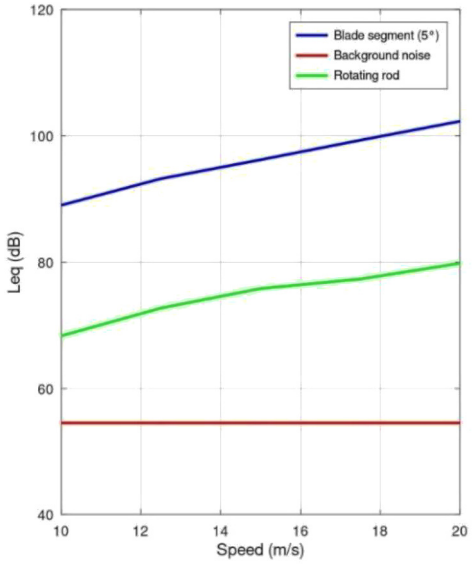


Fig. 10. Dependence of the equivalent noise level on the velocity of the incoming flow

of rotational motion for the model provided a more realistic simulation of actual turbine operating conditions, thereby enhancing the reliability of the acquired data.

Using a test blade segment with a NACA 0012 profile, spectral noise characteristics were analyzed, enabling the assessment of acoustic behavior in the presence of background noise and validating the effectiveness of the proposed approach. A method for separating aerodynamic noise from background noise was also introduced. The study identified consistent patterns relating aerodynamic noise levels to frequency characteristics, specifically highlighting the presence of tonal components in the noise spectrum. Additionally, the influence of rotational speed on the equivalent noise level (Leq) was examined.

The developed experimental setup and analysis methodology can be applied to future parametric studies aimed at reducing noise levels from blade profiles, as well as for the validation of numerical simulation models.

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Методика акустичного експерименту для дослідження аеродинамічного шуму сегментів лопатей вітряних турбін

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Мета. Розробка й відпрацювання методики дослідження аеродинамічного шуму ротору вітряної турбіни та аналіз акустичних характеристик такого шуму на прикладі сегменту лопаті із профілем NACA0012. Робота спрямована на вирішення актуальної задачі зниження рівня шуму вітрових турбін у системах відновлювальної енергетики.

Методика. У роботі використано метод експериментального моделювання аеродинамічного шуму сегменту лопаті вітрової турбіни в лабораторних умовах у безлунній камері. Методика вимірювань відповідає вимогам стандарту ДСТУ ГОСТ ISO 5725-1:2005.

Результати. У роботі розглянуті підходи до дослідження проблеми аеродинамічного шуму вітрових турбін, і розроблено оригінальний експериментальний стенд для дослідження акустичних характеристик шуму сегментів лопатей турбін у безлунній камері. Запропонована методика аналізу акустичних сигналів, що досліджується, і фонового шуму. Проведені вимірювання рівнів шуму та проаналізовані спектральні характеристики звукових хвиль від сегмента лопаті із профілем NACA 0012 в умовах наявності фонового шуму. Показана ефективність даного підходу для проведення акустичних досліджень.

Наукова новизна. Запропонована методика дослідження аеродинамічного шуму є оригінальною й відрізняється від традиційних підходів, що ґрунтуються на використанні аеродинамічних труб із тестовими секціями, інтегрованими в безлунне акустичне середовище. На відміну від методів, де реалізується принцип оберненості потоку та стаціонарне положення моделі, у представленій методиці моделюється обертальний рух лопаті аеродинамічного профілю. Такий підхід дозволяє більш точно відтворити умови роботи ротору вітряної турбіни й отримати експериментальні дані, що краще відображають реальні характеристики аеродинамічного шуму.

Практична значимість. Розроблені методика досліджень та експериментальний стенд можуть бути використані для параметричних досліджень різних профілів лопатей з метою визначення перспективних, із точки зору зниження аеродинамічного шуму, модифікацій лопатей. Результати дослідження також представляють інтерес для верифікації числових методик дослідження аеродинамічного шуму від лопатей турбін.

Ключові слова: *відновлювальна енергетика, вітрові турбіни, аеродинамічний шум, акустичний експеримент, спектри шуму*

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