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Acoustic Study of REpower MM92 Wind Turbines During Exploitation

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The paper presents the current state of knowledge concerning the sources of noise generated by wind turbines, force measurement methodology, and assessment of noise onerousness in this type of installation, on the basis of a study concerning a wind farm with five REpower MM92 wind turbines and the electric power of 2 MW and the sound power level of 104.2 dB(A) each. Particular attention was focused on the often discussed problem of presence of infrasound generated by turbines and on the requirements of the applicable reference methodologies for the measurement of wind speed to 5 m/s, while the turbine reaches its full power at speeds above 10 m/s.

Keywords: wind turbine noise, low frequency noise, airfoil self noise, measurements assessment.

1. Introduction

All the wind turbine generators subject to the study are used in onshore wind parks located in Poland and are often found in close proximity to inhabited areas. Their operating raises questions as to its environmental and health impact, in the context of balancing strict standards in granting environmental permits for new wind farms and supporting renewable energy production nationwide. There has been a number of publications in Poland and worldwide concerning the environmental and health impact of wind turbines operation on nearby residents and natural habitats but these quite often came to contradictory conclusions. This article presents results of a research performed in order to determine the environmental noise impact of a wind farm located in village Łęki Dukielskie (Subcarpathian Province, Southeast Poland). The said wind farm was launched in 2009 and consists of five REpower MM92 wind turbine generators with a total capacity for electric power production of 10 MW.

2. Sources of wind turbines noise

Noise emitted by a wind turbine generator ("WTG") comes from two separate sources: mechanical and aerodynamic ones. The noise of the mechanical origin (transfer of power) occurs in connection with the operation of a generator, gearbox, and rotor and is heard only in the vicinity of the nacelle (i.e., some 100–150 m above the ground level). Further away from the nacelle (and the whole wind turbine) it is indistinguishable from the background wind noise that is audible.

The dominant source of WTGs' emitted noise is of aerodynamic origin occurring out of rotation of the rotor blades which are overcoming the aerodynamic drag. This type of noise can be divided into three components:

- *Low frequency noise*, related to the low (below 200 Hz) frequency of spectrum. It occurs mainly when the rotating rotor blades encounter local air gaps associated with the flow around the tower or change of wind speed;
- *Inflow turbulence noise,* which appears as a result of turbulence or local pressure fluctuations around the rotor blades;
- *Airfoil self noise,* an aerodynamic phenomenon that occurs along the blades (see Fig. 1). This noise is wideband but it also occurs in the form of tone, mainly due to the blunt end of the wing and the airflow through exist slits and holes. With a favourable wind, the rotor blade's tip can move at a speed of 250 km/h (about 70 m/s), resulting in the emission of sound with distinct tonal components in the frequency range of 700–800 Hz (Fig. 2).

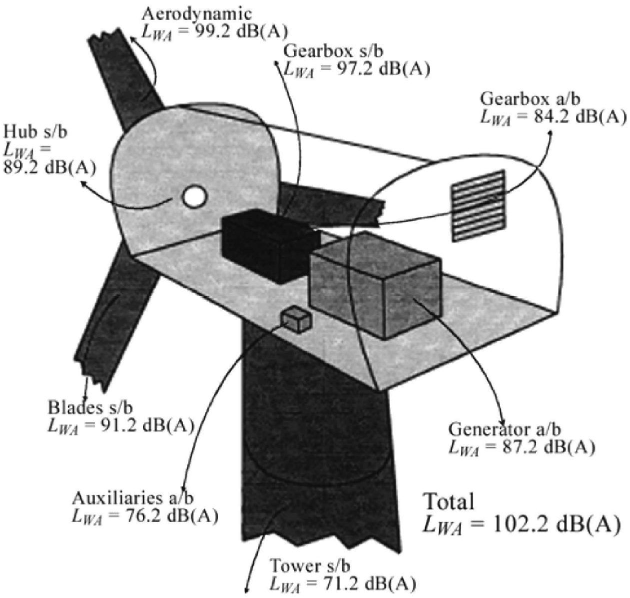

Fig. 1. Components and total sound power level of a 2 MW wind turbine (Rogers, Manwell, 2004).

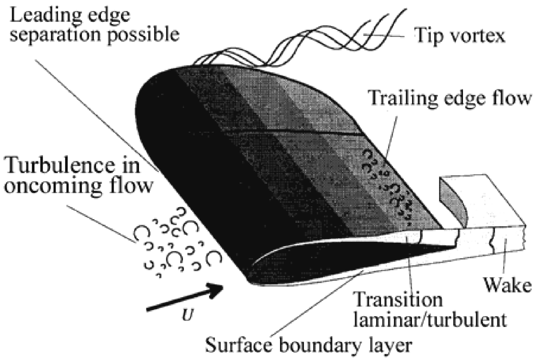

Fig. 2. Schematic of the flow around a rotor blade (Rogers, Manwell, 2004).

According to the data sheets, A-weighted sound power level of wind turbines from different manufacturers can vary from 98 to 108 dB(A) for power units with capacity from 0.5 to 2 MW, with wind speeds of approximately 10 m/s, measured at a height of 10 meters above the ground level (MAGL). Typical Repower MM92 WTG tower heights are 70, 80, or 100 metres. Sample data of wind turbine sound power level as a function of wind speed and the height of the tower are shown in Table 1.

The data in Table 1 show the difference in the dependence of the wind speed measured at height of 10 meters above the ground level and measured at the height of the nacelle. This difference may range from 1 m/s to 5 m/s. This fact is important for assessment of turbine operation. The wind speed (WS) at which the turbine is turned on is usually around 3–4 m/s, the nominal operation range is from 10 to 15 m/s, and the exclusion of the turbine is in the speed range from 20 to 25 m/s. The sound power level of the wind turbine increases by about 5 dB(A) twice, the first time it does during the inclusion of a wind turbine for W10 in the range of 3–4 m/s, and the second time this happens during the nominal operation for W10 in the range of 5–7 m/s (see Table 1). However, due to a high position of the turbine relative to the ground (e.g. for power plants with a power of 2 MW the height of the tower is about 100 m), the sound pressure level at the ground level is much lower and varies according to Eq. (1), proposed by International Energy Agency (1994):

$$L_{pA} = L_{WA} - 10\log_{10}(2\pi R^2) - \alpha R, \qquad (1)$$

where L_{pA} is the A-weighted sound pressure level dB, L_{WA} is the A-weighted sound power level dB, R is the distance from the sound source to the receiver, α is the sound absorption coefficient (depends on the frequency).

Figure 3 shows the theoretical range of the noise generated by REpower MM92 (black solid line) also marking the limits of the night in an “N” as 40.0 dB(A), and for the time of day “D” as 50.0 dB(A) for a single-family housing area according to (Regulation of the Minister of Environment, 2007).

Table 1. Sound power level of the wind turbine as a function of wind speed (W10 is the wind speed at the height of 10 MAGL, WS is the wind speed at the nacelle's height) and tower height (H).

W10 [m/s]	H = 70 m		H = 80 m		H = 100 m	
	L_{WA} [dB]	WS [m/s]	L_{WA} [dB]	WS [m/s]	L_{WA} [dB]	WS [m/s]
3	95.7	4.1	96	4.2	96.4	4.3
4	101.2	5.4	101.4	5.6	101.7	5.8
5	103.1	6.8	103.3	6.9	103.4	7.2
6	104.2	8.1	104.2	8.3	104.2	8.7
7	104.2	9.5	104.2	9.7	104.2	10.1
8	104.2	10.8	104.2	11.1	104.2	11.6
9	104.2	12.2	104.2	12.5	104.2	13.0
10	104.2	13.6	104.2	13.9	104.2	14.5

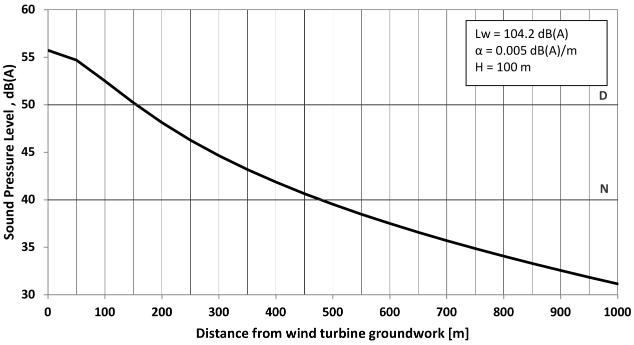

Fig. 3. Theoretical range of the REpower MM92 turbine noise.

The sound pressure level of the background noise is closely related to the wind speed (see Fig. 4), which was indicated in 1999 by Fegeant and confirmed experimentally in 2002 by Rogers and Manwell. The value of the A-weighted sound pressure level perceived by humans depends on the proportion of the wind speed and represents the relationship (2):

$$L_{Aeq} \cong 60 \log_{10}(U), \qquad (2)$$

where U is the wind speed [m/s].

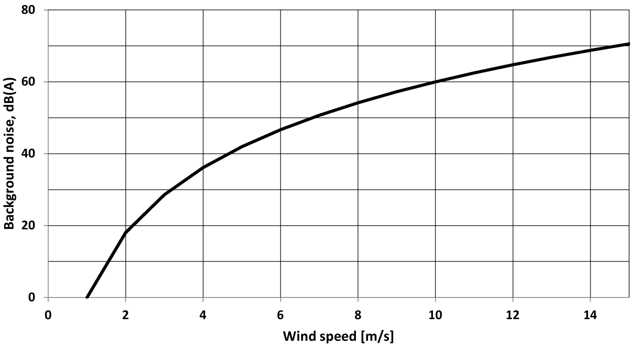

Fig. 4. Sound pressure level dB(A) of the background noise in the function of the wind speed.

Equation (1) and Fig. 3 show that A-weighted sound pressure level at a distance about 150 metres from the turbine tower should be less than 50 dB, and at the distance from 500 meters and further it should be less than 40 dB. Hence, the general recommendation (in Poland) is to locate wind turbines at a distance further than 500 meters from residential buildings.

A-weighted sound power level which was taken for the calculation (104.2 dB(A)) is the maximum power at wind speeds of 12.5 m/s at the height of the nacelle (100 m). Accordingly, the wind speed at 10 MAGL will be about 9 m/s, and probably at 4 MAGL it would be near this value. For this wind speed, the perceived level of the background noise estimated in accordance with (2) will exceed 55 dB(A). Thus, at a distance greater than 100 m from the turbine tower (as well as with the turbine height $H = 100$ m) the level of the sound generated by the wind power working (noise) will be masked by the sound of the wind. The said theoretical assumptions were verified by actual measurements.

3. Permissible noise levels in the environment

The environmental standard of maximum noise levels is provided in the Regulation of the Minister of Environment dated 14 June 2007 (Official Journal No. 120, Item 826; amended in 2012). Under the said Regulation, the acoustic climate assessment is adjusted only for the frequency range of the audible sound by the human (A-weighting curve) (PN-EN 61672:2005). Wind turbines are classified in the category of "Other objects and activities producing noise". Noise limit values are dependent on the type of land zoning and the amount of 50 dB during the day and 40 dB at night for a single-family housing, and 55 dB during the day and 45 dB at night for a farm building. These are the popular zoning categories in the vicinity of wind farms.

Noise limits for infrasound are regulated in Poland only in the context of the work environment by Regulation of the Minister of Labour and Social Policy dated 29 November 2002 (Official Journal No. 217, Item 1833). Equivalent G-weighted sound level related to the 8-hour daily working time or working week should not exceed 102 dB, and unweighted peak sound level cannot exceed 145 dB. There are no documents relating to the assessment of this type of noise in the environment.

4. Methods of measurement of environmental noise

Regulation on requirements for emission values adopted by the Minister of Environment, dated 4 November 2008 (Official Journal 2008, No. 206, Item 1291) determines how to perform noise measurements. One of the points is ensuring that certain weather conditions are taken into account, for which the maximum wind speed is 5 m/s at a height of the microphone (4 MAGL of built-up area and 1.5 MAGL for undeveloped land). In the case of sound measurements of the wind noise, measurements have validity when a turbine works nominally. This happens for wind speeds above 10–12 m/s at the height of the nacelle (70–100 MAGL), which translates to about 7 m/s at a height of 10 MAGL and at a similar speed of 4 MAGL. With the wind speed of about 3–5 m/s at a height of 4 MAGL turbines do not operate at the nominal power and thus are much quieter. The said Regulation provides only one procedure for measuring noise, regardless of the type of industrial noise sources. However, the negative impact of the wind on the measurement of the sound pressure level was covered in the PN-EN 61400-11 "Wind turbine generator systems – Part 11: Acoustic Noise Measurement

Techniques". According to this document, measurement is carried out in at least four points around the plant. The arrangement of measurement points (microphones) around the wind turbine is shown in Fig. 5. The measuring distance R_0 depends on the tower height and diameter of the rotating turbine and it is determined according to the diagram shown in Fig. 6.

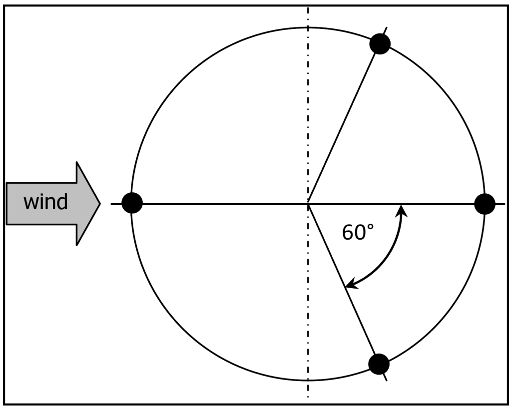

Fig. 5. Arrangement of measurement points (microphones) around the wind turbine.

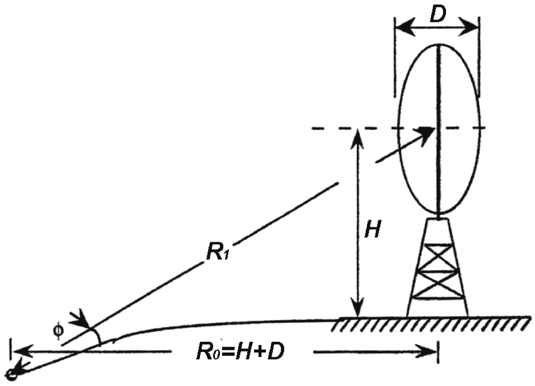

Fig. 6. Distance between the measuring point and wind turbine tower (PN-EN 61400-11).

Microphone, secured by two windscreens, is located on a special circular disc with a minimum diameter of 1 meter located directly on the ground (0.05 MAGL). This is shown in Fig. 7.

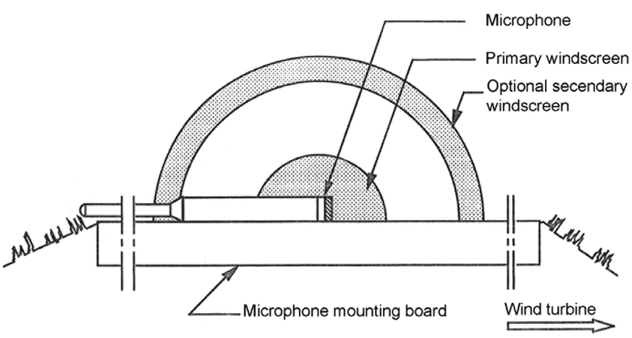

Fig. 7. Mounting of the microphone – vertical cross-section (PN-EN 61400-11).

It is recommended that during the test parallel measurement are made of the equivalent sound level, A-weighted, the period of rotation of the turbine, speed, and wind direction. The duration of one measurement must be at least one minute. Spectrum bands must be set in 1/1 or 1/3 octave. Measurements should include the widest possible range of wind speeds, but they may not differ by more than 2 m/s from the nominal speed. Application of these principles will provide: the sound power level, noise emission level in the function of the wind speed, directionality, noise emissions level in the bands of the 1/1 and 1/3 octave, tonality. The standard (PN-EN 61400-11) also recommends conducting additional measurements (including infrasound, low frequency noise, impulsiveness) for quantitative assessment of wind turbine noise.

5. Acoustic study REpower MM92 wind turbines

The study was conducted in a wind farm in the village Łęki Dukielskie (Subcarpathian Province), installed and turned on in 2009. The wind farm consists of five MM92 Repower wind turbine generators with the electric capacity of 2 MW each. This particular type of wind turbines is used for low and medium wind speeds. Figure 8 shows the view of one of the five turbines.

Fig. 8. REpower MM92 wind turbines in the village Łęki Dukielskie (own photo).

The farm is located on the hills, which are agricultural land, 0.7 miles north of the village Lęki Dukielskie and 1 km east of the villages Myszkowskie (Fig. 9). It is an open area on each side, with particular emphasis on the south, south-west, and west. Figure 10 shows the location of the power plant (E1–E5) and measuring points (1–7) in the field. During the measurements turbine E2 did not work. Therefore, to determine the sound power level, turbine E3 was selected, and a minimal impact of the others (operating wind turbines) for the measurements was assumed.

Fig. 9. Acoustic measurement of REpower M92 wind turbine in the village Lęki Dukielskie (own photo).

Table 2 shows the weather conditions during the measurements.

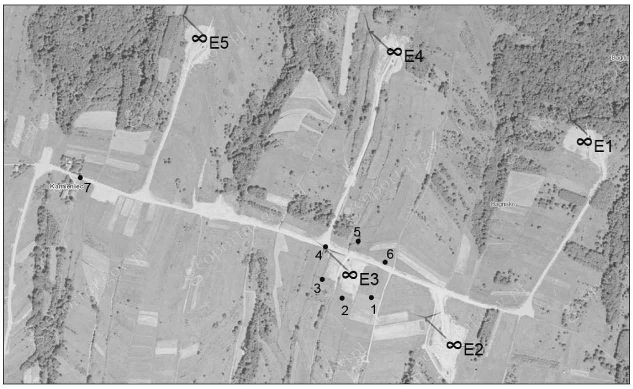

Fig. 10. Location of wind turbines (E1–E5) and measuring points (1–7) in the village Lęki Dukielskie (drawn on the basis of http://www.geoportal.gov.pl/).

Table 2. Weather conditions during the measurements.

	Minimal value	Maximum value	Average value
atmospheric pressure [hPa]	957.8	958.4	958.1
temperature [°C]	6.2	7.2	6.8
humidity [%]	51	68	62
wind speed [m/s]	2.5	9.5	5.1
wind direction	S. SW		

Summary of the results of measurements taken within the power E3 are shown in Table 3. The measurement time at each point was 2 minutes. During each measurement, the speed of the turbine's rotor was estimated. According to the results (Table 3), the highest measured equivalent sound level (L_{Aeq}) is at point 1, where the turbine rotor blade passes the mast from leeward and at point 2 after leaving the rotor blades from the turbine tower zone. The acoustic measurements were made in the 1/3 octave spectral bands in the frequency range from 0.8 Hz to 20 000 Hz. This frequency range covers the audible by humans (20 Hz to 20 kHz) and infrasound range, which issue is one of the strongest arguments posed

Table 3. Results of the acoustic measurements for REpower MM92 wind turbine.

Measuring point	Measurement time [s]	L_{Aeq} [dB]	SEL [dB]	Peak [dB]	Max [dB]	Min [dB]	Turbine speed [rot/min]
1	120	51.3	72.1	73.1	57.7	47.4	14.3
2	120	49.5	70.3	72.9	62.7	42.3	14.0
3	120	41.6	62.4	86.1	55.8	37.2	13.1
4	120	37.1	57.9	62.7	42.8	34	12.5
5	120	43.8	64.6	73.5	66.7	39.8	13.1
6	120	46	66.8	87.9	62.1	41.1	13.7
7	120	37.8	57.9	62.7	42.8	34.0	–

against the construction of new wind farms. Spectra of the sound pressure level for the points 1, 4, 3, 5 are shown in Figs. 11–14. The location of these points and the direction of the wind turbine were selected as shown in Fig. 5. Point 4 is in front of the wind turbine (windward), point 1 is located behind the wind turbine (leeward). A significant part of the acoustic energy is in the frequency range from 0.8 Hz to 200 Hz in the spectra of the sound pressure level (L_{eq} is the uncorrected by human hearing curve). For this band, the sound pressure level (L_{eq}) reaches the highest value at the measurement point 1 (97.2 dB). At the same point, value of the sound pressure level in the frequency range from 250 Hz to 20 kHz is 52.6 dB. For the remaining measuring points this relationship is similar. The calculation results are presented in Table 4. Therefore, it can be concluded that the dominant low-frequency spectrum of the noise is in the infrasound, which remains inaudible to the humans.

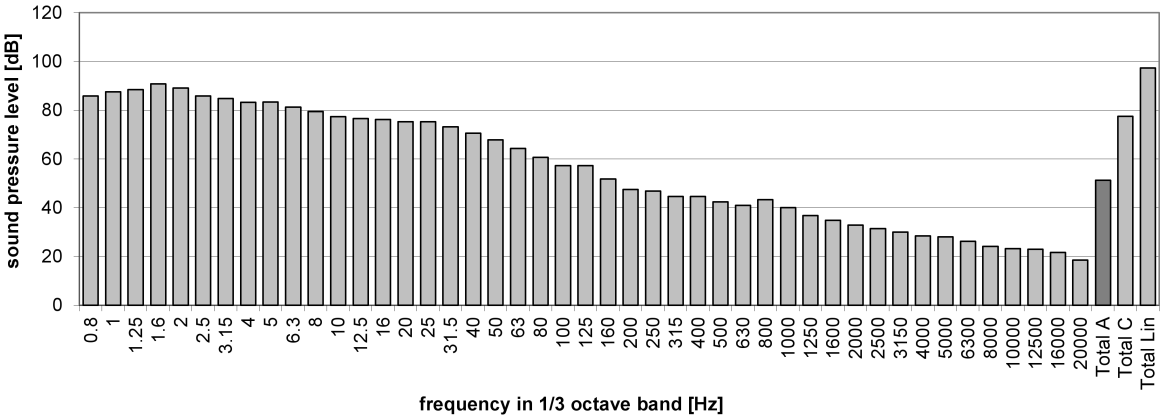

Fig. 11. Spectrum of the sound pressure level at measuring point no. 1.

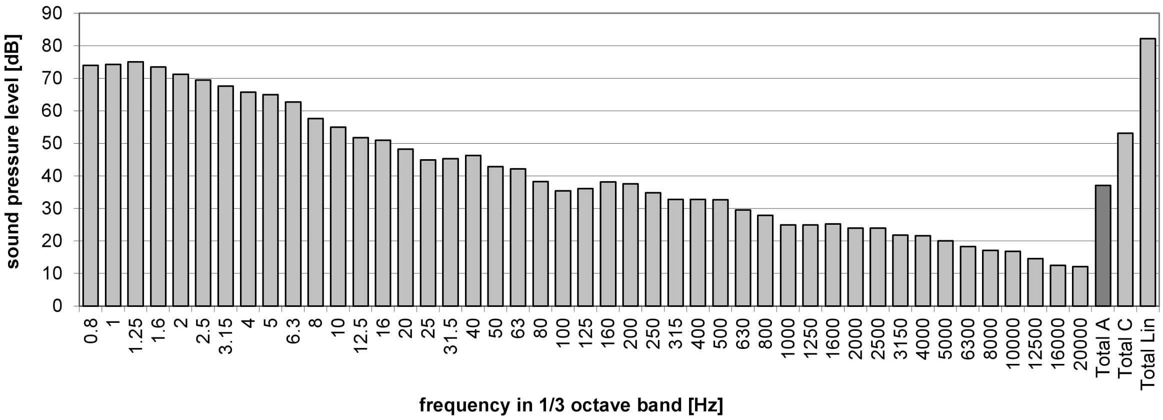

Fig. 12. Spectrum of the sound pressure level at measuring point no. 4.

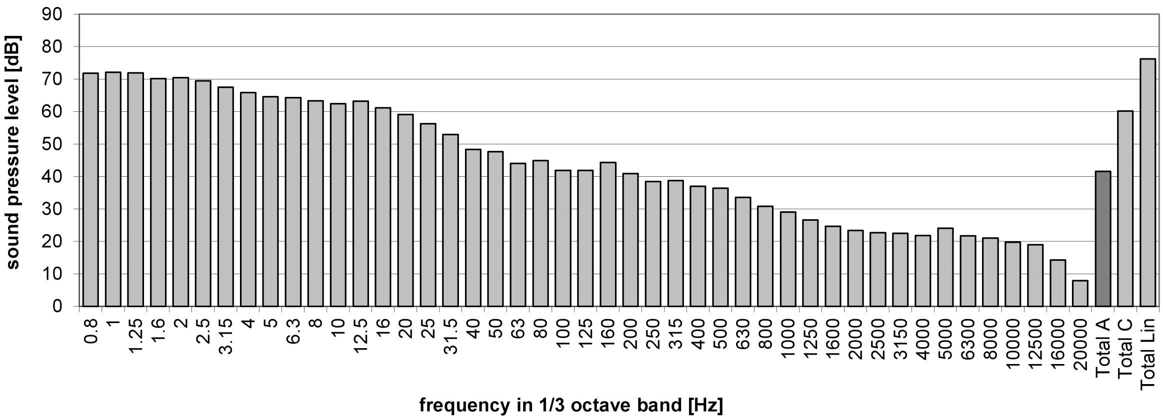

Fig. 13. Spectrum of the sound pressure level at measuring point no. 3.

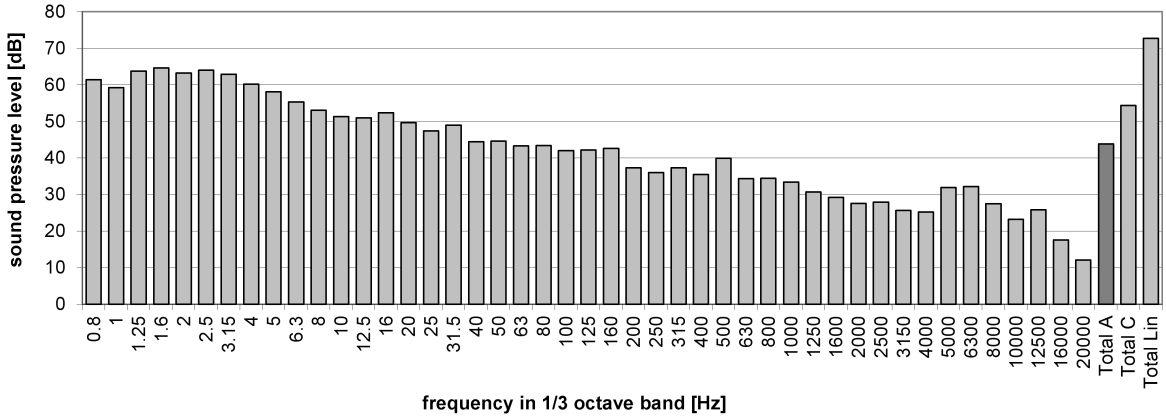

Fig. 14. Spectrum of the sound pressure level at measuring point no. 5.

Table 4. Sound pressure level in the selected frequency bandwidth of REpower MM92 wind turbine.

Bandwidth	L_{eq} [dB]			
	point 1	point 4	point 3	point 5
0.8–20 000 Hz	97.4	81.6	80.1	72.4
0.8–16 Hz	97.1	81.6	80.0	72.2
0.8–200 Hz	97.2	81.6	80.1	72.3
250–20 000 Hz	52.6	40.9	44.8	45.9

To assess the impact of the wind farm (all operating turbines) in the inhabited area, the measurement shown in point 7 was made next to a residential building. The measuring point was about 600 meters away from the nearest turbine operation and approximately 800 m from the next one. Measurement of the sound level at this point (L_{Aeq}) was performed during the operation of the plant E1, E3, E4, E5, and it was 37.8 dB(A) (see Table 3). Because the measuring point was near the two operating turbines, the measured value corresponds to the L_{Aeq} calculated for model of propagation of the two acoustic sources (38.3 dB(A)) (1). The measured value is below the limit value set for the night for this type of area (L_{AeqN} = 40 dB(A)). Thus, there were no exceedances of the limit value laid down in the Regulation of the Minister of Environment dated 14 June 2007 (Official Journal No. 120, Item 826) amended on 01 October 2012 (Official Journal No. 0, Item 1109).

6. Summary

The paper presents the current state of knowledge concerning the sources of noise generated by wind turbines, valid acoustic measurement methodology, and the assessment of noise nuisance in this type of installation, on the example of a wind farm of five REpower MM92 turbines of the 2MW and 104.2 dB(A) sound power level each. Particular attention was paid to the widely discussed issue of the infrasound's presence, as generated by the turbines, and the requirements of the applicable reference methodologies for the measurement of wind speed lower than 5 m/s, while the turbine reaches its full power at speeds above 10 m/s. It was concluded that this type of the wind turbine in the given meteorological conditions does not pose a threat of infringement of the current environmental standards and no higher levels of infrasound were registered.

Acknowledgments

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