Vibrations in Physical Systems Vol.26 (2014)

Infrasound and Low Frequency Noise of a Wind Turbine

Malgorzata WOJSZNIS
Institute of Applied Mechanics, Poznan University of Technology
3 Piotrowo Street, 60-965 Poznań
Malgorzata.Wojsznis@put.poznan.pl

Jacek SZULCZYK
Environmental Acoustics Laboratory EKO – POMIAR
4 Sloneczna Street, 64-600 Oborniki
JacekSzulczyk@eko-pomiar.com.pl

Abstract

The paper presents noise evaluation for a 2 MW wind turbine. The obtained results have been analyzed with regard to infrasound and low frequency noise generated during work of the wind turbine. The evaluation was based on standards and decrees binding in Poland. The paper presents also current literature data on the influence of the infrasound and low frequency noise on a human being. It has been concluded, that the permissible levels of infrasound for the investigated wind turbine were not exceeded.

Keywords: low frequency noise, infrasound, wind turbine

1. Introduction

Research that has been conducted in the world for many years shows that noise can be described as sound below and above so called *hearing threshold*. It can be assumed that the *infrasound*, which cannot be heard by a human being, concerns frequencies below 20 Hz, and the *ultrasound* concerns frequencies above 20 kHz [1]. We receive it as mechanical vibrations of the medium it passes through, transferring energy from the source in the form of acoustic waves. Puzyna in [1] describes infrasound as *infraaccoustic vibrations*. Some investigations show that for some people the hearing level begins already at 16Hz, and sometimes even at 4Hz. Such a phenomenon occurs at appropriate conditions and at a high level of sound pressure [2]. According to standards PN-ISO 7196:2002P, ISO 9612:1997 and PN-Z-01338:2010 [3, 4, 5] the infrasound noise concerns frequencies between 1 and 20 Hz.

The term *low frequency noise* is more and more commonly used to describe the frequency range from 10 Hz to 250 Hz (e.g. according to Polish instruction ITB 358/98) [6]. In other countries this range is defined differently and it is closely related to medical research concerning the influence of infrasound noise on the hearing organ [6, 7].

2. Influence of infrasound and low frequency noise on a human being

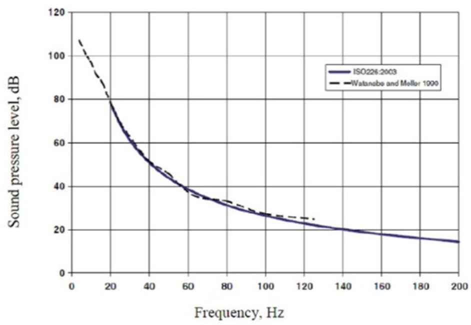
The influence of infrasound on a human being is closely related to conduction of the middle ear and internal ear, i.e. its effect on the hearing organ (*hearing effects*) and on the whole body, and particularly on the nervous system and internal organs *(non-hearing* *effects)*. Infrasound is annoying and its effects appear already when the hearing threshold is slightly exceeded [8].

Figure 1 shows hearing thresholds for infrasound and low frequency noise obtained by Watanabe and Møller [9, 10] set against the values from the ISO:226 2003 standard and compared with the respective levels in other countries [11,12].

Based on Watanabe and Møller's results, Leventhall determined the hearing threshold for infrasound and low frequency sound [10] – Table 1.

Figure 2 shows so called equal annoyance contours for infrasound obtained by Whittla (1972) set against Møller's and Andresen's results (1984) [12] and equal loudness contours from ISO 226: 2003 standard [11].

a)



b)

	Poland	Germany	Netherlands	Denmark Night	Sweden	ISO 226
Frequency Hz	L_{A10} dB	DIN 45680 dB	NSG dB	20dBA	dB	dB
8		103				
10	80.4	95		90.4		
12.5	83.4	87		93.4		
16	66.7	79		76.7		
20	60.5	71	74	70.5		74.3
25	54.7	63	64	64.7		65.0
31.5	49.3	55.5	55	59.4	56	56.3
40	44.6	48	46	54.6	49	48.4
50	40.2	40.5	39	50.2	43	41.7
63	36.2	33.5	33	46.2	41.5	35.5
80	32.5	28	27	42.5	40	29.8
100	29.1	23.5	22	39.1	38	25.1
125	26.1			36.1	36	20.7
160	23.4			33.4	34	16.8
200	20.9				32	13.8
250	18.6					11.2

Figure 1. Hearing thresholds in the infrasound and low frequency ranges
a) acc. to ISO 226:2003, Watanabe and Moller b) in selected countries [9, 10, 11, 12]

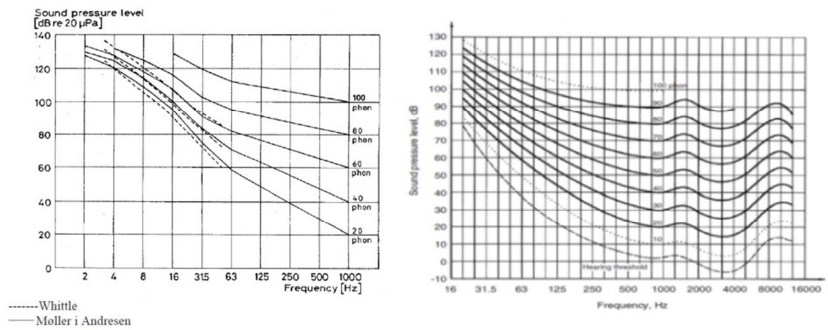


Figure 2. Equal annoyance contours for infrasound and equal loudness contours from the ISO 226: 2003 standard for audible sound [11, 12]

Table 1. Hearing threshold according to Leventhall[10]

Frequency (Hz)	4	8	10	12,5	16	20	25	31,5	40	50	63	80	100	125	160	200
Sound pressure level (dB)	107	100	97	92	88	79	69	60	51	44	38	32	27	22	18	14

Like in case of equal loudness contours for audible sound, the equal annoyance contours for infrasound were obtained using the expressed in phons loudness level based on subjective sensing of sound by the hearing organ. A frequency drop causes sudden increase in audio perception, which means that even at small change the annoyance of infrasound increases. In the range of 127-132 dB a painless constriction is observed in the middle ear. Earache and so called temporary shift of the hearing threshold appear most often at the level of 140 dB for frequency 40 Hz and 160 dB for 3 Hz [13]. At higher frequencies the internal ear can be damaged.

At the levels above 100 dB the perception of vibrations generated by infrasound is similar to the perception of vibrations generated mechanically [14]. Infrasound may be sensed by telereceptors of vibrations located, for example, in muscles, joints and tendons, and so called sensory receptors (mechanoreceptors). In this case the threshold of vibration sensing is higher than the hearing threshold by about 20-40 dB. Landström in [15] claims, that the vibrational perception of infrasound occurs at the level of 124 dB for frequency 4 Hz, for which the hearing threshold equals 107 dB.

The most typical symptom of influence of infrasound and low frequency sound on a human being is the pressure in ears together with the sensation of internal vibration. At the levels of 140-150 dB vibrations of the rib cage cause voice modulation and suffocation in the throat leading to coughing. It can be said that infrasound may cause arhythmia, fatigue and increase in heart rate [13, 16]. All these symptoms may appear after the hearing threshold has been exceeded, which has been confirmed by the research conducted on the deaf [13].

3. Evaluation of infrasound noise under the current regulations

The evaluation of exposure to infrasound noise is made based on spectral analysis in third octave or octave bands using G-weighting [3] developed based on the analysis of hearing perception threshold. Its peak lies at the frequency of 20 Hz, and the average value of the hearing threshold equals 102 dB [17]. It has been observed, that to evaluate low frequency noise the A-weighting cannot be used because it gives too low values [18].

The PN-Z-01338:2010P standard, which defines permissible values of infrasound noise at work-places, being a criterion for annoyance, and a regulation of the Ministry of Labour and Social Policy, where additionally the peak, unweighted acoustic pressure level is determined [4,19] are in force in Poland – Table 2.

Table 2. Permissible values of infrasound noise – annoyance criterion [4]

Evaluated quantity	**Permissible value, dB**
Equivalent, G-weighted sound pressure level normalized to an 8-hour working day, $L_{Geq,Te}=L_{Geq,8h}$	**102**
Equivalent, G-weighted sound pressure level related to a nominal working week, $L_{Geq,Te}=L_{Geq,w}$	**102**
Equivalent, G-weighted sound pressure level during the occupation of a workstation by an employee (at work places for conceptual work requiring particular concentration)	**86**

4. Noise evaluation for a 2 MW wind turbine

A wind farm consisting of several 2.0 MW wind turbines Gamesa G90 with tower height of 100 m and blade length of 45 m was analyzed (Figure 3). The measurements of noise was performed by a research laboratory accredited by Polish Centre for Accreditation.

Figure 3. A 2 MW wind turbine with a total height of 145 m

The obtained results were analyzed paying special attention to evaluation of infrasound and low frequency noise generated by a working wind turbine, located at the edge of the wind farm [23, 24]. The evaluation was made based on standards and regulations being in force in Poland.

Figure 4 shows the equivalent, G-weighted sound pressure levels for the turbine for various distances of measuring points from the turbine and at the wind velocities of 3-4 m/s and 4-5 m/s measured at the height of 10 m above the ground in frequency bands of 1-20 Hz and 0,8–250 Hz. The measuring points were selected at places without any buildings and natural obstacles.

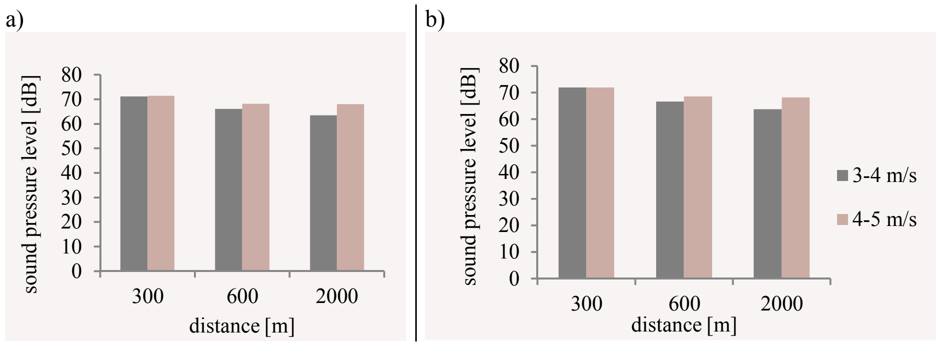


Figure 4. Equivalent, G-weighted sound pressure level for a 2 MW turbine determined based on the standard [3] in the range of a) infrasound and b) low frequency noise

As it can be seen from Figure 4 the annoyance criterion of 102 dB has not been exceeded.

At a distance of 600 m from the turbine, where the closest residential property was located, additional measurements at variable wind velocity were performed. The wind velocity measured at 10 m height can be converted into the velocity at the tower height by means of a coefficient, which equals about 1.45. It means that acoustic measurements were performed for the wind velocity between 4.3 m/s and 13 m/s at the tower height (Figure 5).

Tower height [m]	H = 67m	H = 78m	H = 100m
W_S / W_{10} [m/s]	1.36	1.39	1.45

Ratio between W_S and W_{10} in accordance with IEC 61400-11 standard.

W_{10} [m/s]	H = 100m	
	dB(A)	W_s [m/s]
3	91.4	4.3
4	96.7	5.8
5	101.6	7.2
6	105	8.7
7	105	10.1
8	105	11.6
9	105	13.0
10	105	14.5

Figure 5. Method of conversion of wind velocity measured at 10 meters above the ground W_{10} into the velocity at any tower height W_S [25]

As it can be seen from the tables shown above, the G90 turbine reaches the maximum level of acoustic power for the wind velocity of 6 m/s at 10 m height, i.e. 8.7 m/s at the tower height. The infrasound levels during measurements were generated by the wind turbines for maximum acoustic power (determined according to PN-EN 61400-11) and maximum rotational speed of the turbine [22].

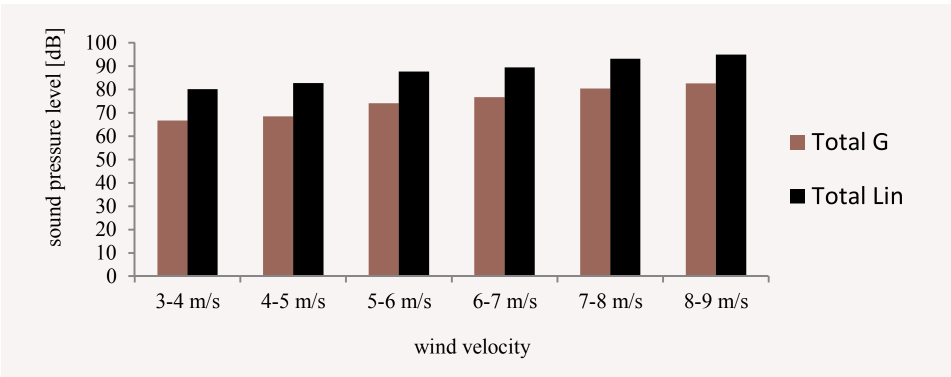


Figure 6. Equivalent sound pressure level for a 2 MW turbine in the infrasonic range for the distance of 600 m

The equivalent sound pressure level for the 600 m distance which can be seen in Figure 6 increases significantly with the increase of the wind velocity. It does not exceed, however, the permissible values specified in Polish regulations.

The obtained results for the low frequency range and the 600 m distance, at different wind velocities has been set against the data from Table 1 (Leventhall), the current hearing threshold in Germany and the 40 phon equal loudness contour from the ISO 226: 2003 standard [10, 11, 12, 21] – Figure 7.

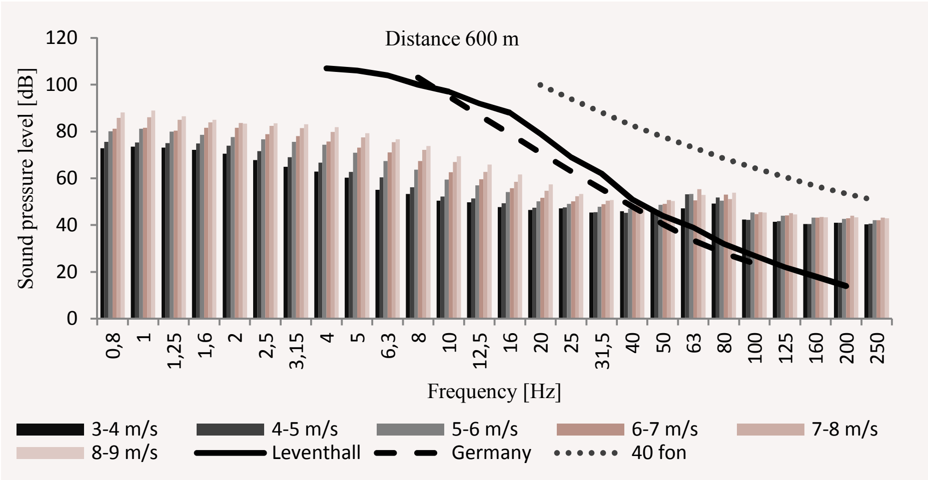


Figure 7. Sound pressure level of a 2 MW turbine for the 600 m distance, set against hearing thresholds

Analyzing the data from Figure 7 it can be clearly seen that in the infrasonic range the levels generated by the turbine working at maximum electrical power and maximum rotational speed are safe. We have different situation at frequencies above 40 Hz, i.e. already in the audible range, where the hearing threshold was exceeded at some places even by 50 %. If, however, we take into account the equal loudness contours [11] for the audible range, and particularly the most frequently used 40 phon one, the values obtained for the turbine in this range are below the threshold.

5. Conclusions

Based on the conducted analyses it can be said, that the investigated wind turbine does not pose any danger to people staying in its vicinity. Such a conclusion can be drawn based on the current regulations related to infrasound and low frequency sound. One should remember, however, that the regulations concern the 8-hour-exposition, and people stay in the area of the turbine continuously, even at night.

The permissible levels in the infrasonic range have not been exceeded. In the low frequency range above 40 Hz it would be necessary to conduct an in depth analysis, because the results are equivocal.

Referring to the report of the American Wind Energy Association and the Canadian Wind Energy Association from 2009 [20] it can be said, that at present there is no scientific evidence, that modern wind turbines generate vibrations perceptible by people and pose any danger related thereto.

Acknowledgments

The work was partially financed by dB-Projekt Sp. z o.o.

References

1. Cz. Puzyna, *Ochrona środowiska pracy przed hałasem, tom I,* Wydawnictwa Naukowo-Techniczne, Warszawa 1981;
2. F. Duck, S. Darby, G. Haar, M. Hanson, G. Leventhall, D. Noble, J. Sienkiewicz, I. Zequir, *Health Effects of Exposure to Ultrasound and Infrasound, Report of the Independent Advisory Group on Non-ionising Radiation*, Documents of the Health Protection Agency, Radiation, Chemical and Environmental Hazards, February 2010;
3. PN-ISO 7196:2002P *Akustyka – charakterystyka częstotliwościowa filtru do pomiarów infradźwięków;*
4. ISO 9612:1997, *Akustyka – wytyczne do pomiarów i oceny ekspozycji na hałas w środowisku pracy;*
5. PN-N-01338:2010P *Akustyka – Pomiar i ocena hałasu infradźwiękowego na stanowiskach pracy.*
6. M. Stopa*, Hałas niskoczęstotliwościowy w górnictwie skalnym*, Prace Naukowe Instytutu Górnictwa Politechniki Wrocławskiej, Nr 134, Studia I Materiały Nr 41, Wrocław 2012;
7. M. Alves-Pereira, N. Castelo-Branco, E. Kotlicka, J.Motylewski, *Low frequency noise legislation*, Inter-noise, Istanbul 2007;
8. K. Marek, *Choroby zawodowe*, Wydawnictwo Lekarskie PZWL, Warszawa 2003;
9. T. Watanabe, H. Moller, *Low frequency hearing thresholds in pressure field and free field*, Journal Low Frequency Noise Vibration 9, pp 106-115, 1990;
10. H.G. Leventhall, *What is infrasound*?, Progress in Biophysics and Molecular Biology 93, pp 130-137, 2007;
11. ISO 226:2003 *Acoustics – normal equal – loudness contours;*
12. H.G. Leventhall, S. Benton, P. Pelmear, *A Review of Published Research on Low Frequency Noise and its Effects,* Report for DEFRA, Department for Environment, Food and Rural Affairs, 2003;
13. A. J. Indulski, *Higiena pracy*, Oficyna Wydawnicza Inst. Med. Pracy, tom II, Łódź 1999;
14. S.D. Smith, *Characterizing the effect of airborn vibration on human body vibration response,* Aviation, Space and Environmental Medicine 73, pp 36-45, 2002.
15. U. Landström, *Laboratory and field studies on infrasound and its effects on humans*, Journal of Low Frequency Noise, Vibration and Active Control 6, 1, pp 29-33, 1987;
16. Z. Damijan, *Zmiany wybranych parametrów biochemicznych i fizjologicznych organizmu po ekspozycji drganiami niskoczęstotliwościowymi*, Diagnostyka, vol. 33, 2005, pp 29 – 34;
17. D. Augustyńska, *Wartości graniczne ekspozycji na infradźwięki – przegląd piśmiennictwa,* Podstawy i Metody Oceny Środowiska Pracy, nr 2(60), s. 5-15, 2009;

18. H. Seungki, K. Jaehwan, K. Kyutae, L. Soogab, *Laboratory study on low-frequency noise weighting curve based on the acceptability limit,* Istanbul, Turkey, Inter-Noise 2007;
19. Rozporządzenie MPiPS z 29 listopada 2002 r., *w sprawie najwyższych dopuszczalnych stężeń i natężeń czynników szkodliwych dla zdrowia w środowisku pracy;*
20. D.W. Colby, R. Dobie, G. Leventhall, G. Lipscomb, R.J. Mccunney, M.T. Seilo, B. Søndergaard, *Wind Turbine Sound and Health Effects An Expert Panel Review*, American Wind Energy Association and Canadian Wind Energy Association, December 2009;
21. A. Rogers, J. Manwell, S. Wright, *Wind Turbine Acoustics Noise*, Renewable Energy Research Laboratory, University of Massachusetts at Amherst, 2006;
22. PN-EN 61400-11:2004+ A1 *Turbozespoły wiatrowe – Część 11: Procedury pomiaru hałasu;*
23. J. Szulczyk, C. Cempel, *Hałas turbin wiatrowych w zakresie infradźwięków*, Monitoring Środowiska 2010, Kraków Maj 2010.
24. J. Szulczyk, C. Cempel, *Analizy symulacyjne propagacji dźwięku farm wiatrowych*, Monitoring Środowiska 2010, Kraków Maj 2010.
25. IEC 61400-11 2002-12 Wind Turbine Generator Systems – Part 11: *Acoustic Noise Measurement Techniques*