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Comparison analysis of noise generated by wind turbines with the other noise source in outdoor environment

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Abstract The paper presents a comparison analysis of the noise generated by wind turbines and the one generated by a ventilation shaft of a working coal mine. The aim of the research was to compare the frequency and amplitude distribution of those sources, especially in the infra range. The ultimate aim it is evaluate possible environmental impact on human annoyance or severity. During the research noise signals were recorded utilizing low frequency microphones, shielded by windscreens. Microphones were localized at the heights of 0.0 m, 1.5 m (approximate location of a human ear in a standing position) and 4 m. Additionally, a measurement position of a microphone in relation to the ground surface was observed. Measurements at ground level were performed according to the standard PN-EN 61400-11:2013-07 and in vertical position, where the microphone was mounted "upside down" with the grid flush with the board. The possible influence of wind speed was also monitored. The results of the measurements are discussed.

Keywords: wind turbines, infrasound, human annoyance, sound propagation.

1. Introduction

The problem of evaluating the effects of infrasound on human health is considered important and many laboratories and research centres have undertaken efforts to establish annoyance contours in the infra range. Infrasound at the intensity levels that may cause annoyance is quite common in our daily surroundings, but, though a few countries have introduced measurement procedures and hygienic limits, there is a deplorable lack of experimental facts to rely on [1]. What is more, the available results cannot satisfactorily explain a number of infrasound complaints or produce recommendations for a limit on the exposure to infrasound [2]. Therefore our goal is to attempt to answer this question. The physiological and psychological effects of infrasound are also very important and particular studies are described and discussed in Refs. [3, 4]. One of the major problems when performing measurement of noise generated by wind turbines is the influence of wind. For better characterization of noise sources it should be monitored [5] and correction due to wind speed estimated, as was undertaken in the research realized in Port Ryerse in Canada [6].

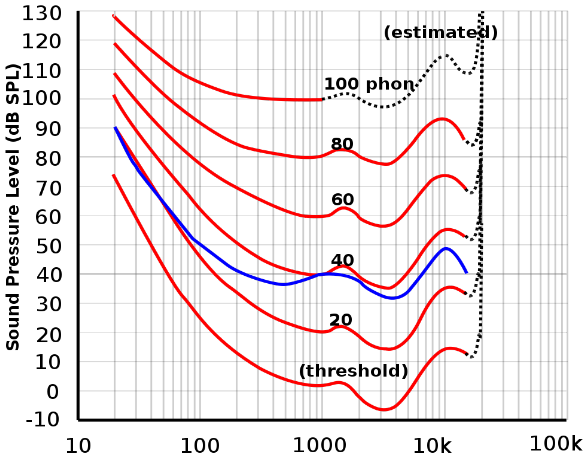

Figure 1. Equal loudness contours (red) from ISO 226:2003 revision together with the contour for 40-phons from original ISO standard (blue).

In the following sections comparison of noise sources is presented, in particular the noise generated by a ventilation shaft of a working coal mine and the noise generated by wind turbines. The main focus is directed to low frequency range in the aspect of possible exceeding the SPL threshold. The relevant equal loudness contours from ISO 226:2003 revision [7] are presented in Fig. 1.

2. Method of recording noise stimuli

The research approach was to measure and record simultaneously noise signals with low frequency microphones, shielded by windscreens, localized at the heights of 0.0 m, 1.5 m (approximate location of a human ear in a standing position) and 4 m. For localization at height 0.0 m (ground level) a microphone was mounted in a vertical position "upside down", with the grid flush with the round board, and in a horizontal position according to the standard PN-EN 61400-11:2013-07. The microphone was mounted on the plate asymmetrically to reduce the influence of the edges of the board. The measurements were performed using Brüel & Kjær PULSE measuring system. In measurement chain Brüel & Kjær and GRAS microphones were utilized, types: 4133, 40AN, and 40AZ (3 pieces). The measurements were performed at two places: near a ventilation shaft of a working coal mine (two sessions) and on a wind turbine farm. In each case the measurements were repeated several times and in different configurations. The results of those measurement sessions were analyzed and compared. The broad band 1/3 octave analyses were utilized in the range 1 Hz – 20 kHz. The example of a measurement point is presented in Fig. 2. Additionally the influence of a measurement height was investigated and results from measurements performed at heights: 1.5 m, 2.0 m, 2.5m, 3,0 m, 3.5 m and 4.0 m were compared. The wind speed was monitored at intervals of 1 s and wind direction was observed. In Figs. 3 and 4 the measurement locations for both investigated sources are shown.

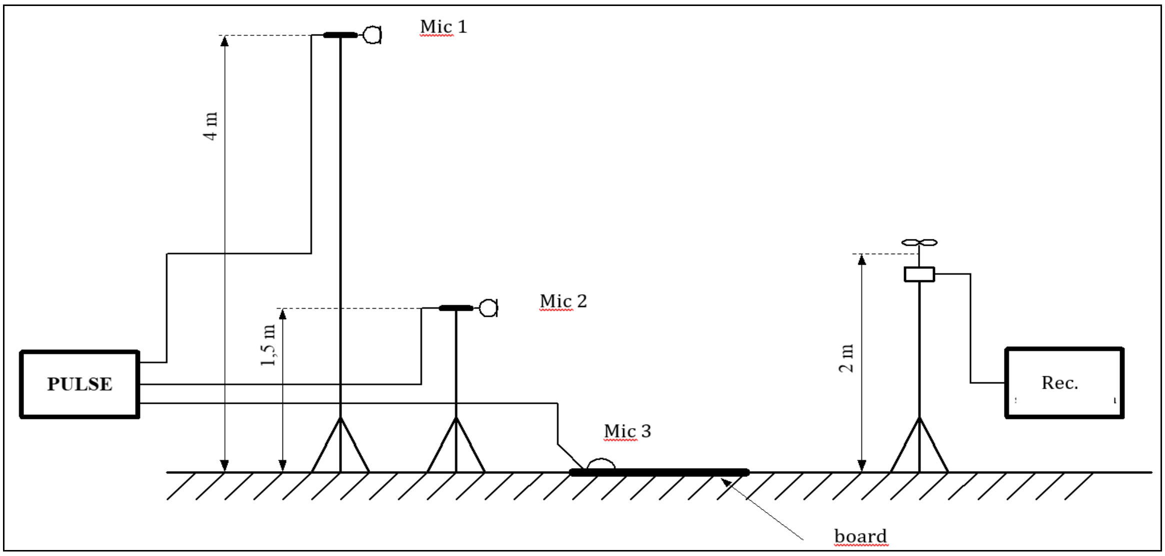

Figure 2. The example position of microphones during the test.

Figure 3. Field measurement near the ventilation shaft of a working coal mine.

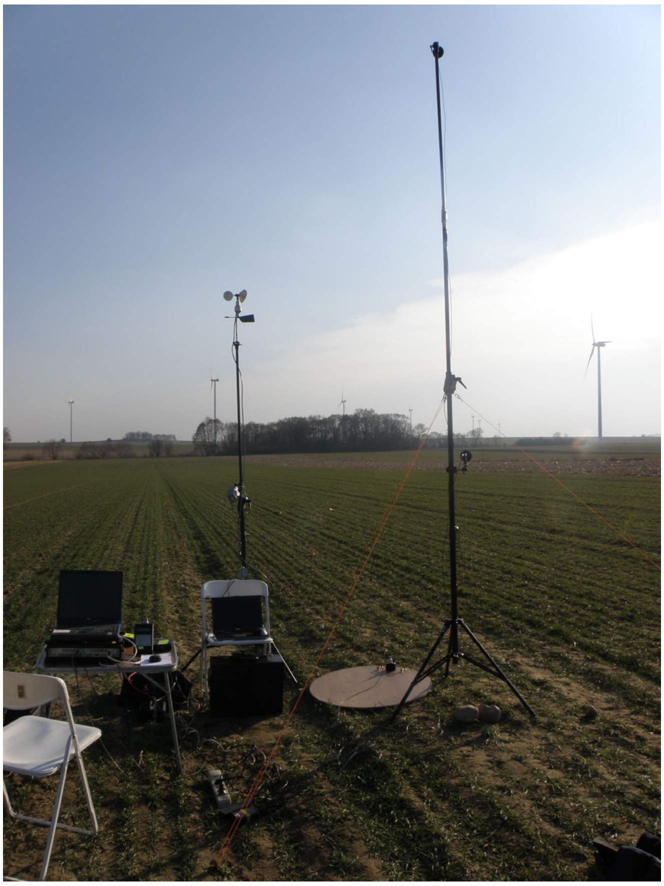

Figure 4. Field measurement of wind turbines.

3. Analysis of results

3.1. One-third octave band spectra of the ventilation shaft of a working coal mine

In order to check and validate the measurement system the research was realized near the ventilation shaft of a working coal mine. Measurements were performed at different heights: 0 m, 1.5 m and 4.0 m. For a microphone mounted on the circular board (0 m) the measurements were performed both in vertical and horizontal positions (the same microphone). The 1/3 octave band spectra are presented in Figs. 5. For both mounting techniques the data are comparable, except in the range below 5 Hz. That was observed in other recordings, so we may infer that the mounting technique makes the difference. Wind speed was continuously monitored. For presented data the wind speed was quite stable with average value ranging from 2.3 m/s to 2.4 m/s.

Figure 5. Comparison between vertical and horizontal positions of a microphone mounted on circular board.

During the second session, at the ventilation shaft of a working coal mine, additional task was undertaken, namely the assessment of the influence of the microphone position (height). It was realized in presumably stable wind conditions. The results - 1/3 octave band spectra are shown in Fig. 6. The wind speed values for consecutive measurements are presented in Table 1.

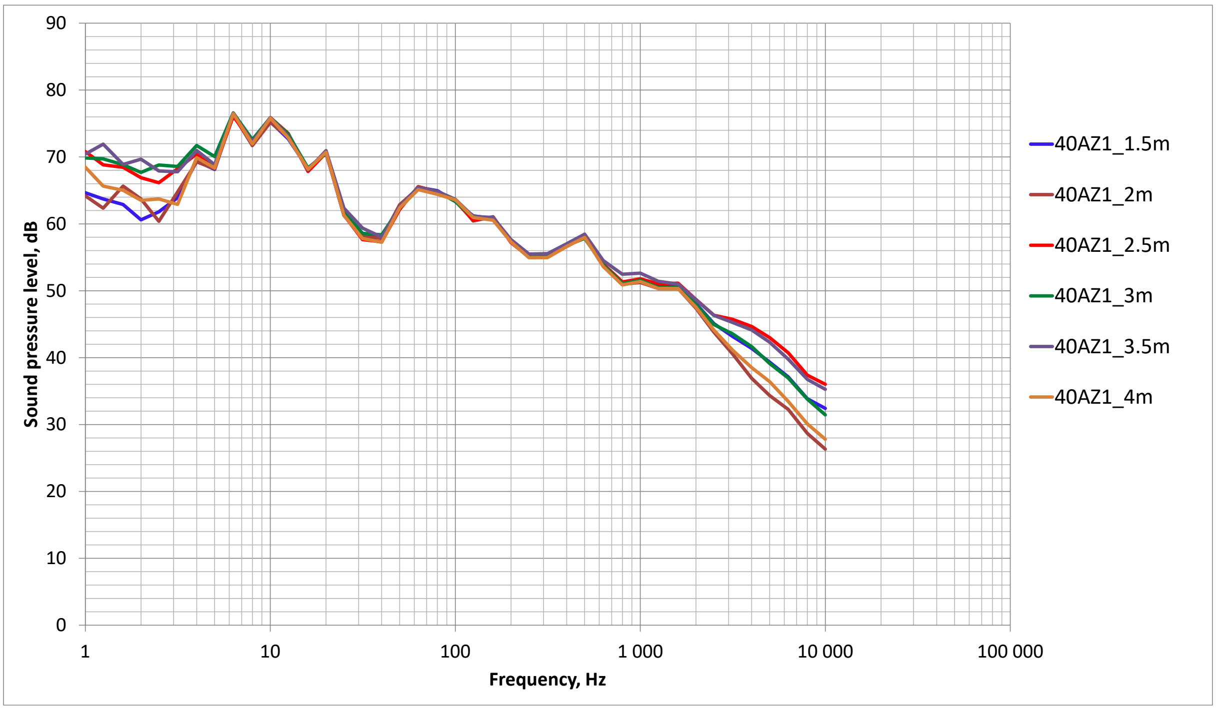

Figure 6. The test for the influence of the measurement height.

Table 1. Comparison of wind speed for different measurement heights.

Measurement height [m]	**Average wind speed** [m/s]
1.5	2.2
2.0	2.1
2.5	2.1
3.0	1.6
3.5	1.4
4.0	1.7

We may infer that there is no much influence of the position (height) of the microphone, except in the range up to 5 Hz where probable instability of the sound source was the cause. At higher frequencies, above 2 kHz, the difference may be attributed to a slight difference of recorded wind speeds or a greater influence of back ground noise (SPL levels below 45 dB).

3.2. One-third octave band spectra of the wind turbines farm

The research was continued at the wind turbines farm where essential recordings were collected. Measurements were performed at heights: 0 m (vertical mounting), 1.5 m and 4.0 m. Wind speed was also monitored. The measurement point was localized at the distance of 750 m from the nearest wind turbine and is shown in Fig. 4 in Sect. 2. The point was placed in the perpendicular direction to the axis of the closest turbine rotor.

There were two main phases of the measurements:

1) all wind turbines were working,
2) only the nearest wind turbine was working.

The results – 1/3 octave band spectra for those two phases for the microphone mounted on the circular board (0 m) are presented in Fig. 7. The values of sound pressure level (SPL) are given in Table 2. For the measurement phases the results are very similar especially in the lower frequency range. A slight difference at the higher range could be caused by the influence of other noise sources (measured sound pressure levels at that range were below 40 dB) or a slight difference in wind speed. The wind speed measured at height 2.7 m ranged from 2.6 m/s to 3.7 m/s. The results also show that the nearest wind turbine had the main influence on the measured signals at that point.

Table 2. Sound pressure levels (SPL) at 1/3 octave bands - a microphone mounted at ground level.

No	**Frequency**[Hz]	**All turbines working**	**The nearest turbine working**	**No**	**Frequency** [Hz]	**All turbines working**	**The nearest turbine working**
1	1.0	60.6	59.9	23	160.0	37.5	35.5
2	1.3	59.4	59.4	24	200.0	37.1	34.9
3	1.6	59.7	59.0	25	250.0	37.2	34.6
4	2.0	58.9	57.9	26	315.0	36.1	33.3
5	2.5	58.2	57.5	27	400.0	35.1	31.6
6	3.2	58.1	57.1	28	500.0	34.6	31.3
7	4.0	56.9	56.2	29	630.0	32.4	30.5
8	5.0	55.5	55.0	30	800.0	29.6	29.1
9	6.3	53.7	53.6	31	1000.0	27.5	28.4
10	8.0	52.6	52.1	32	1250.0	24.8	27.5
11	10.0	51.1	50.4	33	1600.0	21.4	27.0
12	12.5	49.6	49.0	34	2000.0	17.1	25.0
13	16.0	49.1	48.1	35	2500.0	17.5	27.0
14	20.0	49.7	47.6	36	3150.0	16.8	27.5
15	25.0	48.7	45.5	37	4000.0	16.8	27.8
16	31.5	45.9	43.7	38	5000.0	16.5	27.7
17	40.0	43.4	43.9	39	6300.0	16.9	27.5
18	50.0	43.6	44.7	40	8000.0	16.2	25.1
19	63.0	42.1	43.4	41	10000.0	15.3	22.8
20	80.0	39.9	40.6	42	12500.0	16.1	19.4
21	100.0	38.8	39.9	43	16000.0	17.2	18.4
22	125.0	38.3	37.8	44	20000.0	18.7	18.9

It should be noticed that main energy of recorded signals is localized in lower frequency range. The comparison is shown in Table 3 where the sound pressure levels (SPL) were calculated accordingly for the ranges 1 Hz – 20 Hz and 1 Hz – 20 kHz.

Table 3. Comparison of calculated values of sound pressure levels.

Microphone type 40AZ, height 0.0 m			
All turbines working		The nearest turbine working	
1 Hz - 20 Hz	1 Hz - 20 kHz	1 Hz - 20 Hz	1 Hz - 20 kHz
Sound pressure level, dB			
68.3	68.4	67.6	67.7

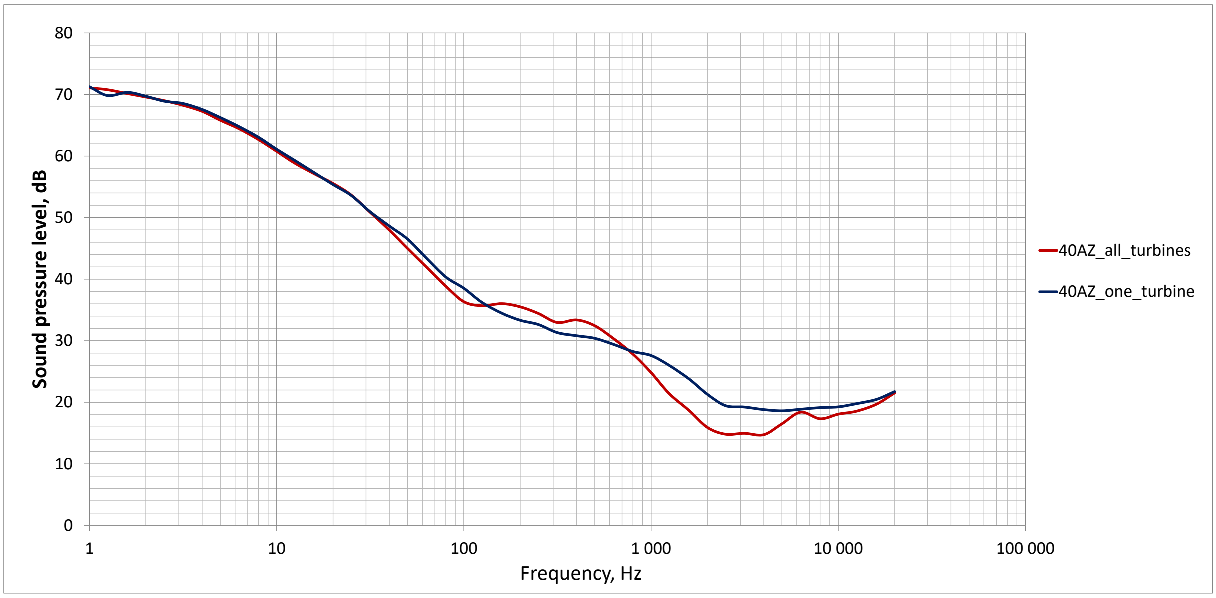

Figure 7. Measured 1/3 octave band spectra for an infrasound recording, measurement phases.

In order to assess the possible annoyance of noise generated by investigated wind turbines the comparison between signals measured at the ventilation shaft of a working coal mine and at the wind turbines farm is shown in Fig. 8. The results are presented for an example case for the same location of a microphone – placement on a board (0.0 m height). Additionally, the reference to ISO 226 threshold and that estimated by Moller and Pedersen in the infra sound range [8, 9] is made. We may comment that as far as audible aspects of annoyance are examined, the noise generated by wind turbines is not perceived as problematic. Probably other aspects as amplitude modulation and visual factors play a greater role.

Presenting the above results we should also take into account an uncertainty of our measurements. For calculation of the expanded uncertainty it was assumed that measuring equipment fulfiled accuracy grade 1 (calibrated) and that environmental conditions were stable. Taking that into consideration, for the sound emission of the investigated object the expanded uncertainty may be approximated as 1.4 dB. If the measurement conditions were unstable, the expanded uncertainty would be much higher and approximate 4.2 dB.

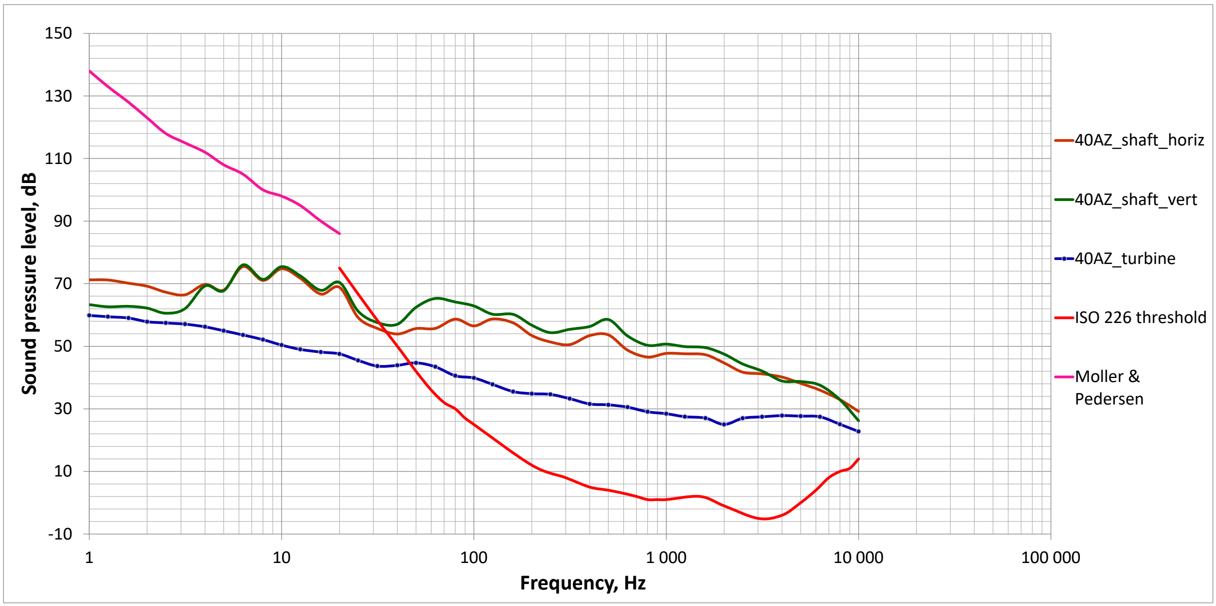

Figure 8. Comparison between measurements at ventilation shaft and on turbine farm versus ISO 226 threshold and estimated by Moller and Pedersen in the infra sound range. Microphone mounted on circular board.

4. Conclusions

The performed measurements gave satisfactory results, as far as repeatability is concerned. They also provided important experience necessary in wind turbines noise measurements. It seems important that the energy of generated sound is mainly localized in lower range, below 20 Hz. As such sound is inaudible by human ear the research should be continued to reveal the nature of its impact on the human body.

The research made by Central Institute for Labor Protection [10]) revealed that infrasonic noise at workplaces in offices requiring employee's special attention focus cannot exceed 86 dB for 8 hours duration. Here the levels of analyzed signals are well below ISO 226 threshold and that estimated by Moller and Pedersen. However they are permanent and should be investigated [11, 12]. It would be interesting to make a survey among the residents of the area neighboring the ventilation shaft about their perception of that noise, but formal problems may be a barrier. Performing measurements for higher wind speeds also seems crucial.

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Additional information

The authors declares that there is no competing financial interests and that all material taken from other sources is clearly cited and that appropriate permits are obtained.

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