Analysis of Wind Energy Potential and Vibrations Caused by Wind Turbine on Its Basement

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This paper deals with study of wind energy potential and experimental measurement of vibrations caused by wind turbine. Study area was wind park Horní Loděnice – Lipina. To obtain frequency distribution of wind speed, two models were used for calculation. Experimental seismological measurement was performed in near surroundings of the wind turbine. At low wind speed without significant wind gust, only negligible vibrations were measured.

Key words*: wind turbine, wind energy potential, wind map, experimental measurement, vibration velocity*

Introduction

Traditionally, the wind power has been used in windmills on the territory of the Czech Republic. The first documented construction of a windmill in historical regions of Bohemia, Moravia and Silesia dates back to 1277. The windmill was located in garden of the Strahov Monastery in Prague. The first modern-style wind turbines (WTs) appeared at the end of the 1980s. However, the first boom occurred between 1990 and 1995, and further expansion came at the beginning of the new millennium (according to http://www.alternativni-zdroje.cz/vetrne-elektrarny.htm, http://www.spvez.cz/pages/vitr.htm). In the Czech Republic, currently more than 150 WTs are registered, and several dozen small WTs are used privately in the households and small enterprise sector (spring 2012). In total, 217 MW of wind power has been installed in the Czech Republic until 2011. In 2011, the total production reached 397 GWh, which would cover consumption of energy in approx. 113,000 households ((http://csve.cz/). Wind turbines used in the Czech Republic are of several types and stand individually, in small groups or form so-called "wind parks (farms)." The situation regarding the WTs in the Czech Republic is described e.g. in Cetkovský et al. (2010) and http://csve.cz/cz/aktualni-instalace.

The measurement introduced in this article was realized in autumn 2012 in the wind park Loděnice – Lipina that contains 9 WTs and, from the European point of view, can be considered a smaller park. Despite that, it is currently the biggest realized project in the territory of Moravia and the second biggest project in the Czech Republic (http://www.vehl.cz/?lang=cz&cat=2&article=16). The first analysis of vibrations measured in this locality in 2011 was introduced in Kaláb (2012). This contribution deals with geological and wind conditions at the given locality and interpretation of new seismological measurements.

Wind park Loděnice – Lipina

The project preparation started in 2003. At the end of 2004, the EIA (Environmental Impact Assessment) analysis report was submitted and the whole EIA process was completed in March 2006. Consequently, municipal development plans were changed and zoning and building permission proceedings were initiated – this was completed at the end of 2007. Construction of infrastructure was initiated in April 2008 and works on foundations of the actual WTs, transformer station and cable route began in following summer. In May and the first half of June 2009, surveyors were able to observe construction of the WTs. Testing operation of the WTs started in July 2009. In the project framework, the technology was supplied by the company Vestas (according to http://www.vehl.cz/?lang=cz&cat=2&article=16).

The wind turbine Vestas V90 – 2MW, manufactured by Danish company, is mounted on a tower with rotor axis at 105 m a.g.l.; rotor diameter is 90 m and length of each blade 44 m. The area of a circle covered by the blades is 6,362 m^2. Altogether, the WT has the maximum height of 150 m. The WT starts to operate when the wind speed reaches 4 m/s and shuts down when the speed hits 25 m/s. The shut-down is done by putting the blades at a flag angle and it is also supported by shoe brakes, which stop the device immediately and lock it afterwards. Foundation of the WT (Fig. 1) is formed by reinforced concrete and covered with layer of soil.

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The biggest diameter of the regular hexadecagon is 16.4 m; thickness of its edge is 1.7 m and increases toward the centre up to 2.7 m at the foot (http://www.vehl.cz/?lang=cz&cat=2&article=19).

Fig. 1. Foundation of the WT Loděnice – Lipina (adopted from: http://www.vehl.cz/?lang=cz&cat=3&article=19).

The wind park Loděnice – Lipina is located at the top of Oldřichovský Hill (628 m above sea level) and Slunečná Hill (627 m above sea level). The hills are formed by ore deposits of Horní Benešov strata (Paleozoic era, Carboniferous, Visean), i.e. reinforced sediments, usually fine-grained or medium-grained. Propagation velocity of longitudinal seismic waves of these rocks is between 1.5 and 4.5 km.s^{-1}. On the surface, not very thick deluvial rock-clay to clay-rock sediments of Quaternary (Holocene) age are present (Fig. 2). In the area, there is no significant anomaly of physical fields as documented by detailed geophysical maps 1:50,000 (Bouguer anomaly map, aeromagnetic map, aero-radiometric map).

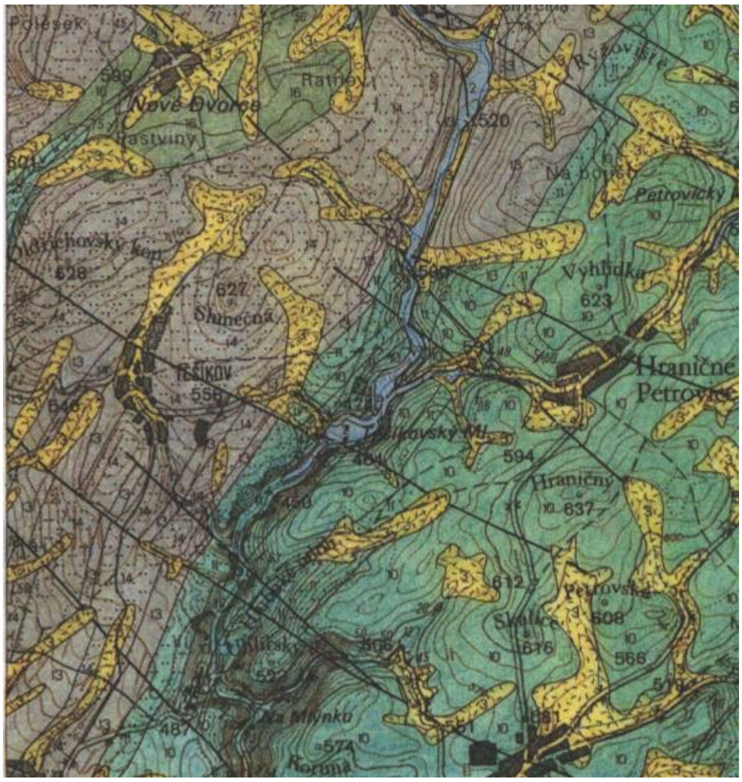

Fig. 2. Detail of the local geological construction. Basic units of Oldřichovský Hill and Slunečná Hill; colour range (numbers in map): 3 – deluvial rock-clay to clay-rock Quaternary sediments (Quaternary, Holocene); 10 – alteration of slates, siltstones, and very fine ore deposits (Paleozoic era, Carboniferous, Visean); According to: © Czech Geological Survey, 2012.

Wind potential analysis – used approach

Wind conditions in the area of the wind farm Horní Loděnice were evaluated using methodology developed at the Institute of Atmospheric Physics Academy of Sciences of the Czech Republic, v.v.i. The modelling system is regularly used in wind resource assessment studies of sites prospective for construction of WTs. Automated version of this method was also applied for calculation of wind map of the Czech Republic (http://www.ufa.cas.cz/imgs/DLouka/vetrna_mapa.gif) and for analysis of technical and realizable potential of wind power in the Czech Republic (Hanslian et al., 2008, Hanslian and Pop, 2008).

The approach involves calculation of the wind conditions by two different models. The models are applied individually with respect to their known issues and limitations affecting the results in the particular location. The final calculation of wind climate conditions is based on the synthesis of both results.

The first is the PIAP - a numerical flow model of atmospheric boundary layer (Svoboda et al., 2012, Svoboda, 1990, Svoboda and Štekl, 1994). The set of weather patterns to be simulated by the model is defined by parameters of inflow lateral boundary and corresponds to idealized meteorological situations. Using a reference station situated inside the model domain, the individual measured values are linked to suitable simulated patterns. Time series at the target site is determined by the difference between wind direction and ratio of the wind speed between the reference station and the target site in the corresponding simulation. The resulting wind climate at the site is calculated from such virtual series of wind speed and direction.

The second method is the so-called "hybrid model VAS/WAsP" (Hanslian and Pop, 2008, Hanslian et al., 2012). The model consists of the WAsP model (Troen and Peterson, 1989) developed in Danish Risø National Laboratory for the purpose of wind resource assessments and of the 3D interpolation method VAS (Sokol and Štekl, 1994, 1995). The calculation of the model VAS/WAsP is performed in three steps. During the first step, the effects of local topography on wind measurements are calculated by WAsP. The model evaluates the impact of surface roughness, orography and local obstacles. As a result, the generalized characteristics of wind climate (so-called "wind atlases") over available wind measurement sites are obtained. Such "wind atlases" are acquired for individual points and consequently interpolated using the method VAS, taking into account the effect of altitude on average wind speed. The result is a map of the spatial distribution of the generalized characteristics of the wind climate over the territory of the Czech Republic. The last step is final calculation performed by the model WAsP that involves correction of the generalized characteristics of the wind climate with respect to the local topography. Compared to the PIAP model, the VAS/WAsP model does not rely on one reference station. Instead, it integrates a multitude of measurements provided by the entire network of available wind measuring stations and wind masts.

Wind potential analysis – calculation with models PIAP and VAS/WAsP and discussion of the results

The models PIAP and VAS/WAsP were applied at the centre point of studied wind farm, at coordinates 49°45'20.51"N, 17°21'28.13"E. The station Dukovany was used as the reference for the PIAP model, even when closer options exist. The selected station, however, has more suitable location with simple surrounding topography and comparably high quality of measurements. Tab. 1 and Fig. 3 and 4 show results of both models at the height of 10 m a.g.l., i.e. at the height of the standard reference measurements.

Tab. 1. Parameters of wind speed at the height of 10m given by the PIAP and VAS/WAsP models.

	Average wind speed [m/s]	**Weibull distribution**	
		A [m/s]	**k**
PIAP model	4.52	4.8	1.36
VAS/WAsP model	4.40	4.6	1.9

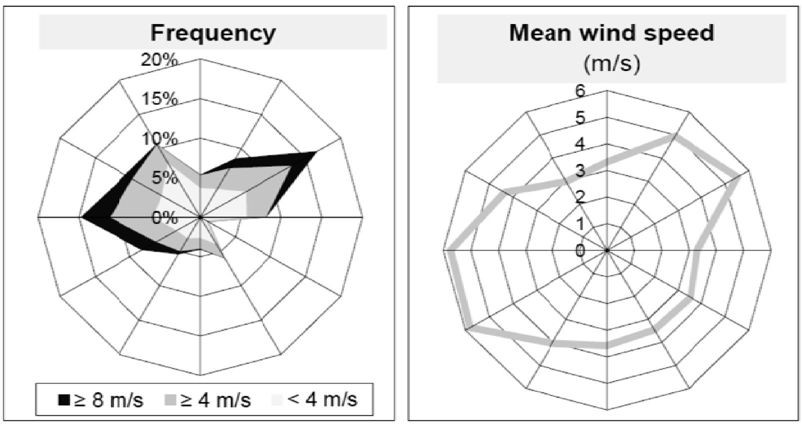

Fig. 3. Wind rose at the height of 10 m according to the PIAP model.

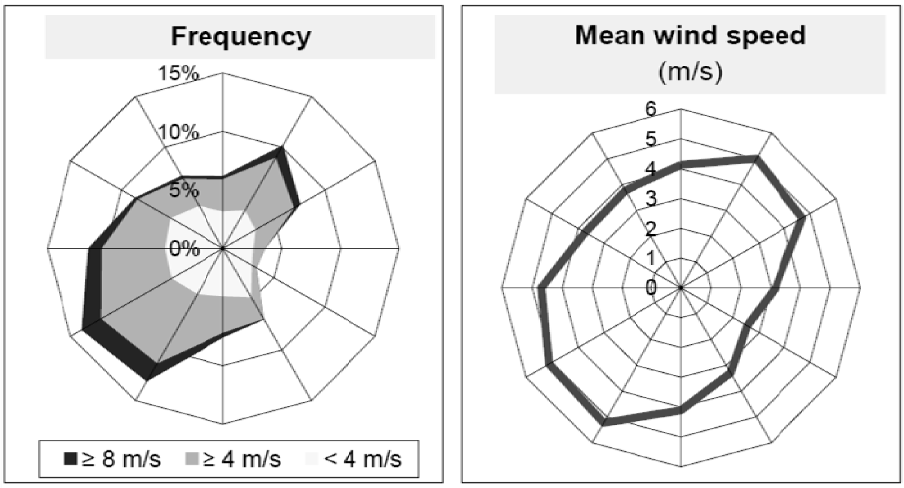

Fig. 4. Wind rose at the height of 10 m according to the VAS/WAsP model.

As it is shown in Table 1, both models give similar results in terms of the average wind speed. Conversely both predicted shapes of wind speed frequency distributions differ, as documented by parameter k of Weibull distribution. The modelled wind roses are slightly tilted from each other. While the prevailing wind directions in the outputs of PIAP are west and east-northeast, it is rather southwest and northeast in the results of VAS/WAsP. Based on our knowledge about the most significant issues and limitations of both models, we conclude that

- we are not aware of any fact leading to a significant underestimation or overestimation of average wind speed predicted by VAS/WAsP model at the site Horní Loděnice;
- the average wind speed predicted by PIAP model is affected by two contradictory effects. Firstly, the coarse model grid resolution leads to the "flattening" of the ridge, where the assessed site is situated. The "flatter" ridge would result in lower positive orographical effects above the ridge top and, consequently, to the lower wind speed at the assessed site. However, despite this reduction, the ridge (or more exactly the rim of Nízký Jeseník plateau) still remains a very significant feature in the model orography. Secondly, it has been experimentally found that PIAP overestimates the wind speed above terrain features of that size, so overestimation of predicted wind speed at the site should be expected. As the latter effect is expected to be more significant at the site, we expect small overall overestimation of PIAP model result;
- PIAP model typically underestimate the value of shape parameter k of the Weibull distribution (i.e. it overestimates the extremity of wind speed distribution);
- both models can be considered as comparably plausible at Horní Loděnice site in terms of the wind rose.

Wind potential analysis – expected wind conditions at Horní Loděnice

Based on the above-mentioned discussion, an artificial "wind atlas" was created with following rules:

- the average wind speed and its frequency distribution was based on VAS/WAsP model;
- the wind rose was calculated as an average of wind roses given by VAS/WAsP and PIAP.

The final calculation of wind conditions at the site was performed by the WAsP model. The results are summarized in Fig. 5 – 7 and Table 2.

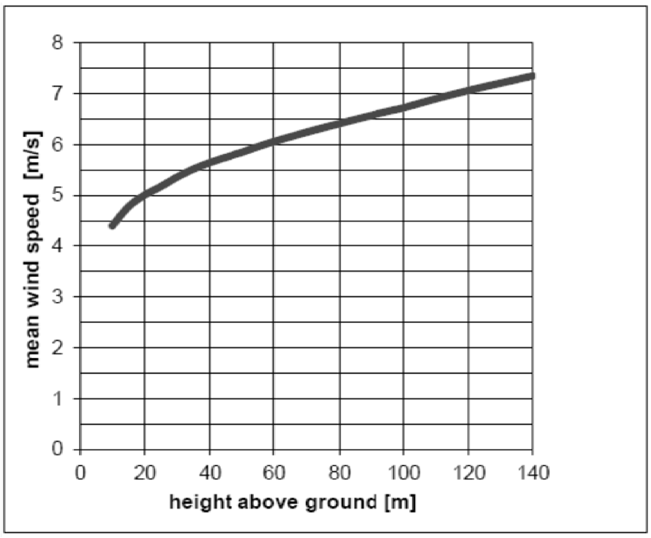

Fig. 5. Predicted vertical profile of wind speed.

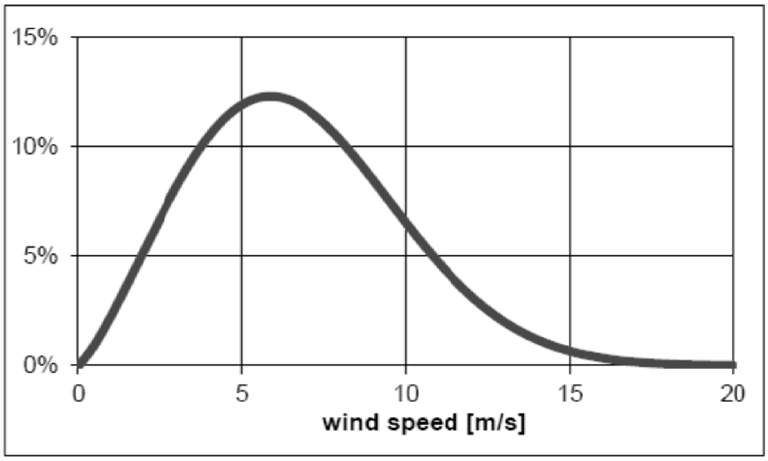

Fig. 6. Predicted frequency distribution of the wind speeds at the height of 100 m.

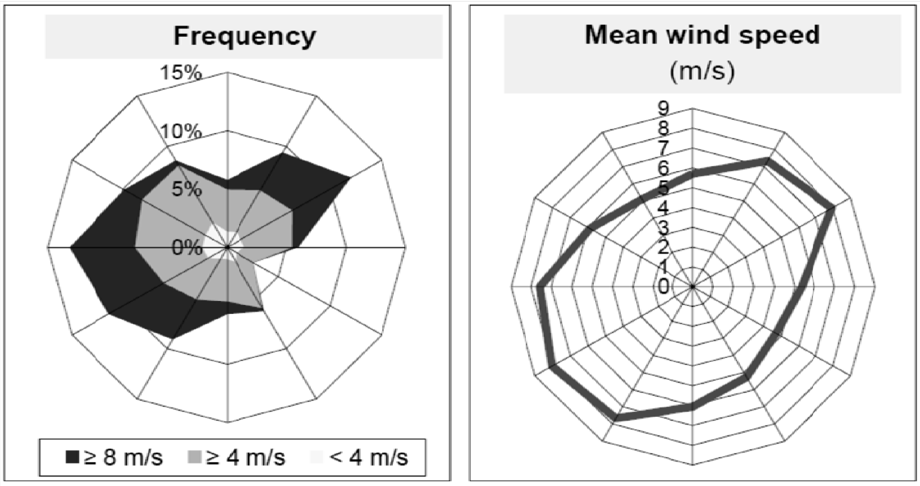

Fig. 7. Predicted wind roses at the height of 100 m.

Tab. 2. Resulting parameters of wind speed at the height of 100 m.

Average wind speed [m/s]	**Weibull distribution**	
	A [m/s]	**k**
6.73	7.6	2.26

Following the general rule in the surface layer of atmosphere, the average wind speed increases with height at site Horní Loděnice . At the height of wind turbines around 100 m above the ground, the average wind speed 6.7 m/s is expected. The highest occurrence and also speed of the wind is expected from west, southwest and northeast.

These results are related to one calculation point. In order to get an idea of spatial distribution of average wind speed, a calculation of wind conditions was performed by WAsP model in a grid with horizontal resolution of 50 m (Fig. 8). Higher wind speed can be, unsurprisingly, expected above more elevated and more exposed sites. The highest wind speed at the western part of the domain could be, however, slightly overestimated as WAsP tends to exaggerate positive orographic effects at highly exposed sites on summits, ridges or terrain edges with steep slopes.

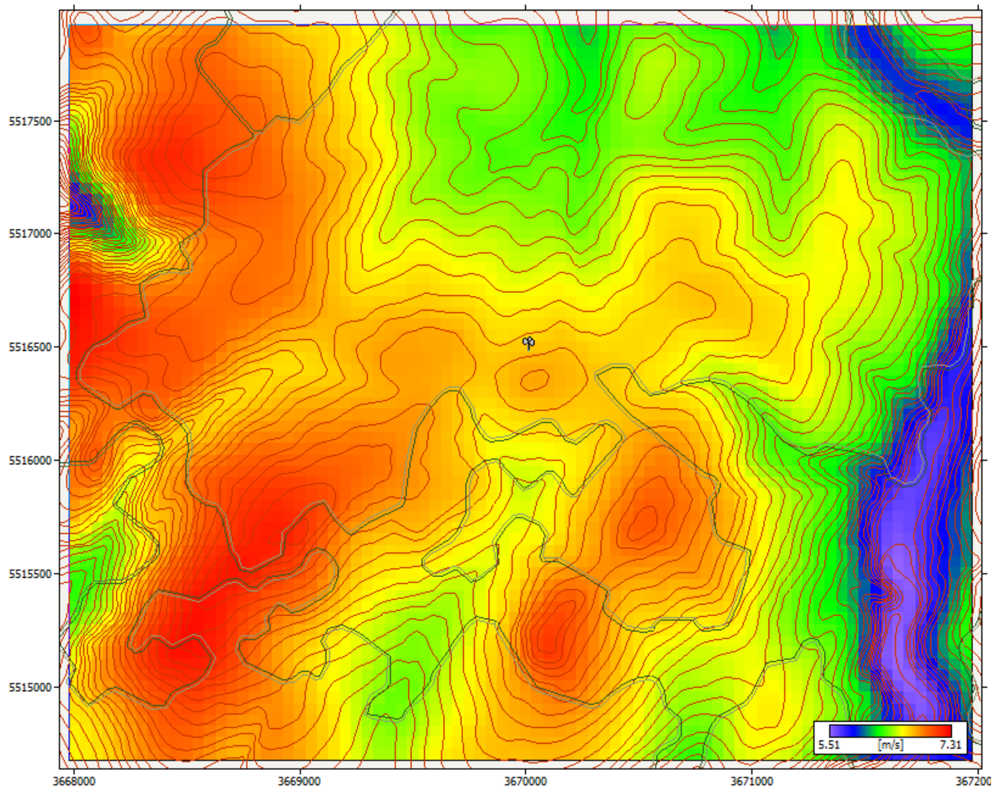

Fig. 8 . Distribution of average wind speed at the height of 100 m over the area of the wind farm Horní Loděnice.

Experimental measurement

Experimental measurement of vibrations caused by the WT was done on 11.10.2012 before noon. The wind speed was variable, predominantly very low. In several periods, strong wind blasts occurred (Fig. 9). It is assumed that more intensive vibrations correspond with the wind blasts and do not occur while the wind is steady. Horizontal component N was directed to the tower of the WT; horizontal component E was oriented perpendicularly with previous direction; component Z was vertical.

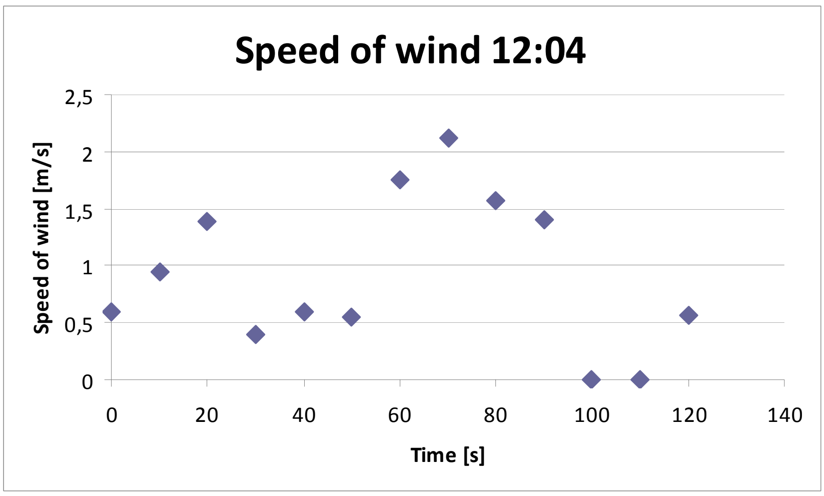

Fig. 9. Example of wind speed measurement (anemometer EXTECH INSTRUMENTS, type HD300) at the locality at the height of 2 m above the ground.

Measurement of demonstration of tower vibrations was executed by placing a sensor on metal staircase leading inside the tower of the WT; deck anchored to the tower approx. 2 m above the ground (Fig. 10). Maximum amplitudes of vibration velocity measured at this point were variable; maximum values measured on all three components were comparable and commonly achieved 0.9 mm/s and max. up to 2.75 mm/s. Frequency analysis of the signal measured at this point shows three more significant peaks in spectra; on frequency 13 – 14 Hz for Z and N, and 9 – 11 Hz for E; other peaks occurred on 28 – 29 Hz and 39 – 40 Hz for all three components. Local increasing of harmonic vibration demonstration can be detected in recordings; in these local increasing, the above-mentioned maximum amplitudes of vibrations can be found.

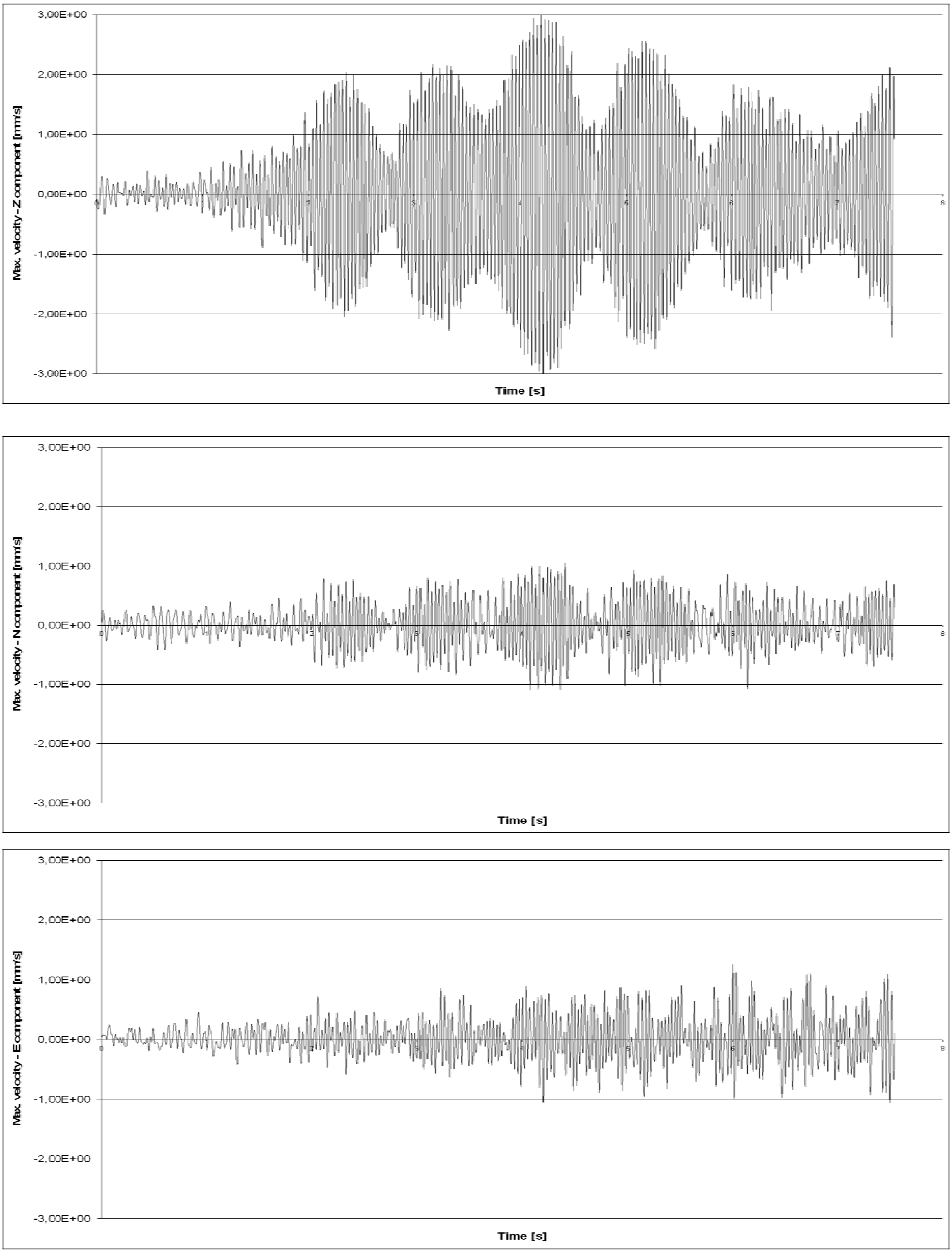

Fig. 10. Wave pattern of vibration velocity on metal staircase; horizontal axis – relative time [s] (start of this record - 09:20:57,60 local time), vertical axis – vibration velocities [mm/s], top-down: Z, N, E component.

The second measurement was executed on a circle, 2 m from the tower. During this measurement, eight stations were used, i.e. angular distance between the stations was 45o. The sensors were placed on grown soil surface after removal of grass. Orientation of sensor elements was identical as in the previous case, i.e. horizontal elements N were directed on the tower of the WT. Common values of vibration velocity measured at individual points were comparable and in range of 0.009 – 0.015 mm/s. Maximum amplitudes of vibration velocity measured on the circle profile were variable in close range – for Z elements 0.03 – 0,021 mm/s, for horizontal elements N and E 0.021 – 0.018 mm/s. Data analysis from the view of detected increased/decreased vibration values, e.g. due to direction of propeller turning, was negative.

Frequency analysis of data measured on the circle around the tower also showed no changes regarding the position of the propeller. In the spectrum, no such significant frequencies were measured as in the course of measurement on metal staircase, however, several well detectable dominant frequencies were measured: 18 – 21 Hz, 32 – 35 Hz and 50 Hz (impact of network grounding). During some time periods, also other dominant frequency peaks were detected, e.g. 40 Hz. More detailed processing of the measured data in time-frequency area can be executed with use of modern numeric methods, e.g. use of wavelet transformation (e.g. Klees and Haagmans, 2000, Lyubushin, 2007, Lyubushin et al., 2004). Study of this type that deals with noise measurements in the area of mine-induced seismicity was published by Kaláb and Lyubushin (2008).

Regarding the fact that measured maximum of wind speed represents only half of average speed of wind according to the above-stated models, it can be expected that caused vibrations can also achieve higher values. Also the fact that during the measurement, no significant wind blasts were recorded must be considered

Conclusion

The aim of this contribution is to present results of measurement of seismic loading caused by operation of wind turbine (WT) in its surrounding. Such seismicity falls into category of technical vibrations, which are, especially lately, initiators of apprehension in people and sometimes also source of construction object damage, e.g. Pandula et al., 2010, Lednická and Kaláb, 2011, Kaláb et al., 2012, Petřík et al., 2012. The article introduces results of experimental seismological measurements taken at the locality Horní Loděnice – Lipina, Olomouc Region. In this wind park, vibration samples were recorded on the metal staircase leading inside the tower of the WT and on the circle located 2 m from the tower. At low wind speed without significant wind gust, only negligible vibrations were measured. At individual measuring points and elements, average and maximal values of vibration speed and more significant frequency peaks were deducted.

The article summarizes observations from one measurement only. After acquisition of larger dataset in various localities, it will be possible to produce more detailed studies of wave field in the surroundings of the WT based on change of parameters of soil or rock environment. These measurements will provide input data for numeric modelling of the given problem, resp. enable determination of seismic loading of the WT at the seismically endangered territories.

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