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Analysis of Vibro-Acoustic Signals Generated during Operation of Micro Wind Turbines

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Results of a measurement and analysis of vibro-acoustic signals generated by two low power vertical-axis wind turbines that are installed on the roof of the Electric Power Institute at Opole University of Technology are presented in the paper. The study considers a Darrieus and a Savonius type wind turbines of rated power 1 kW each. For registration of the vibrations of the turbine mast three uniaxial accelerometers and a measurement equipment from Brüel & Kjær were applied. The measurement setup is presented in the paper. A comparative analysis of the registered data in the time and time–frequency domains was performed. Results depict changes in the recorded signals in time and frequency under different meteorological conditions, i.e. for different wind speed values. Based on the achieved results significant differences in the mast vibrations of the two kinds of wind turbines were stated.

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1. Introduction

Installation of domestic micro wind turbines becomes currently more and more popular. Low-power turbines are generally divided into two groups: Darrieus and Savonius type, but there exist also a lot of variations and combinations of these forms. Operation of wind turbines is connected with many issues, which have important impact on the environment. This includes inter alia generation of infrasound noise and vibrations [1–16]. High power wind turbines have been already tested in a large extent, however this is not the case for low power wind turbines. Our research team is paying particular attention to generation of noise and vibration by electric power devices [1–9]. Currently, we deal also with measurement and evaluation of noise and vibrations generated by low-power wind turbines [10–16]. Authors' overall goal is to investigate the mast vibrations and their impact on the building and people working in it.

2. The object under study and measurement setup

The study considers two small vertical axis wind turbines (VAWT) of types Savonius (turbine 2) and Darrieus (turbine 5) both of rated power 1 kW. The plants are mounted on the roof of Electric Power Institute, Opole University of Technology, Poland.

The measurements were carried out using an experimental setup from Brüel & Kjær consisting of three uniaxial piezoelectric charge accelerometers of type 4514, which were connected to a LAN-XI measuring device, type 3050-A-060, belonging to the PULSE devices series. For data recording a dedicate software PULSE Data Recorder was used which enabled for simultaneous and circular registering of vibrations on all three channels. Acceleration values (acoustic vibrations) in m/s^2 were recorded in form of runs of duration of 5 s. The sampling rate was equal to 65535 Hz. Furthermore, a 0.7 Hz digital filter was applied on the measured signals. This has enabled for later analysis of signals in a broad range: from low-frequency vibrations up to 32 kHz. The vibrations were measured on the bottom of the turbine towers, which are installed in the buildings loft. The X and Z axes represent horizontal vibrations, and the Y-axis vertical vibrations. For analysis of measured signals the MATLAB environment was used. Measurements have been performed on 11th November 2012 for the turbine 2 and on 14th December 2012 for the turbine 5.

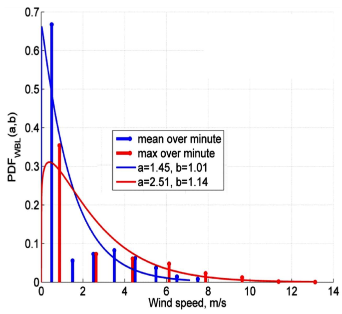

Fig. 1. The distribution of wind speed calculated with Weibull probability density function during measurement of vibro-acoustic signals generated on turbine 2 on 11th November 2012.

The meteorological conditions (the wind speed) were measured by the DAVIS-Vantage Pro2 weather station instrument. Wind speed was measured every minute during measurements; the over minute average and the maximal values were recorded for later analysis. Based on the achieved wind speed data, the Weibull probability density functions (PDF) (1), were calculated for both measuring days

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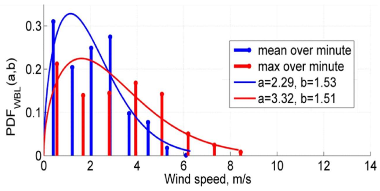

Fig. 2. The distribution of wind speed calculated with Weibull probability density function during measurement of vibro-acoustic signals generated on turbine 5 on 14th December 2012.

$$\mathrm{PDF_{WBL}} = ba^{-b}x^{b-1}\,\mathrm{e}^{-(x/a)^b}, \quad (1)$$

where a — scale parameter, b — shape parameter of the distribution.

In Figs. 1 and 2 wind speed distributions calculated for the two measuring days: 11th November and 14th December 2012 are shown. Each figure depicts both the mean and the maximal wind speed distributions, while the scale and shape parameters are applied in the figure legend. In general during measurements there occurred moderate wind speeds with few wind gusts up to 12 m/s.

3. Results presentation

The analysis of results was performed in the time, frequency, and time–frequency domains. In the time domain the maxima of signal acceleration were estimated for each run. This has enabled for better association of maximal mast vibrations, generated by turbine operation, to the particular wind speed values occurring during measurements. Example time runs of signals measured on the three axes are presented in Figs. 3 and 4, for the turbine 2 and turbine 5, respectively. The signal maxima estimated for the whole measuring day are presented in Figs. 5 and 6, for the turbine 2 and turbine 5, respectively.

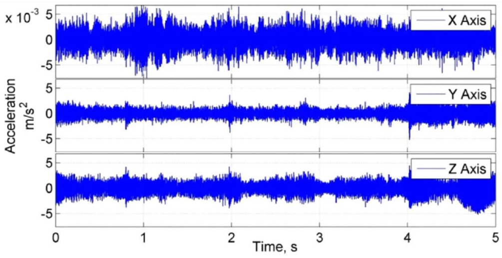

Fig. 3. Example time runs of vibro-acoustic signals generated by turbine 2.

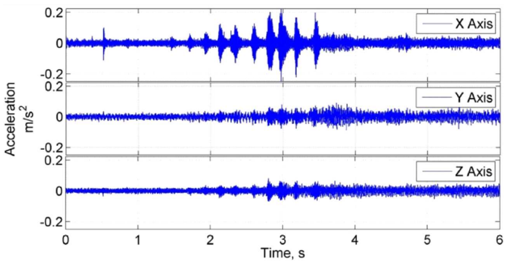

Fig. 4. Example time runs of vibro-acoustic signals generated by turbine 5.

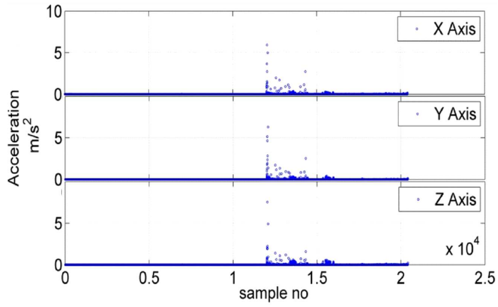

Fig. 5. Maxima in the amplitude of vibro-acoustic signals generated by turbine 2.

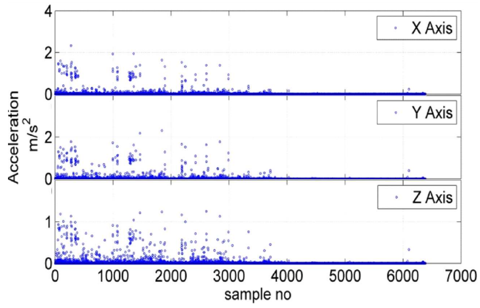

Fig. 6. Maxima in the amplitude of vibro-acoustic signals generated by turbine 5.

In the time–frequency domain we have performed the short time Fourier transform (STFT) analysis and analyzed the acoustic structures occurring in the measured signals during operation of both considered wind turbines. Example spectrograms for the three axes are presented in Figs. 7 and 8, for the turbine 2 and turbine 5, respectively.

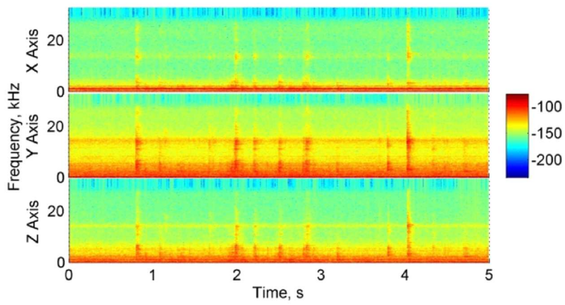

Fig. 7. Example spectrograms of vibro-acoustic signals generated by turbine 2.

Analysis in the frequency domain included also the MUSIC method. The spectrum was evaluated for 10 sub-

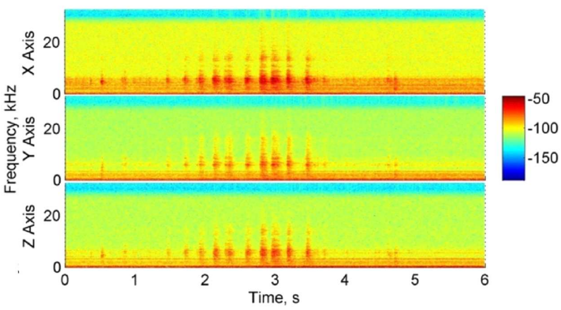

Fig. 8. Example spectrograms of vibro-acoustic signals generated by turbine 5.

spaces, making possible to determine the five main frequency components included in it. Based on the analysis of extrema occurring in the achieved pseudo spectrum, one can state about the most significant frequency components occurring in the vibro-acoustic signals generated during operation of considered wind turbines. In Figs. 9 and 10 example results of the MUSIC analysis performed for vibro-acoustic signals gathered on the three mast axes are shown.

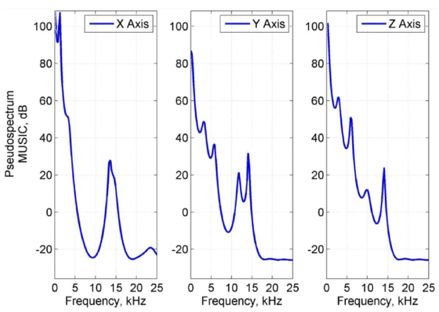

Fig. 9. Example MUSIC pseudospectra of vibro--acoustic signals generated by turbine 2.

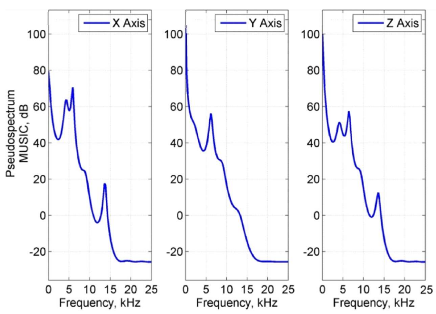

Fig. 10. Example MUSIC pseudospectra of vibro--acoustic signals generated by turbine 5.

4. Discussion and summary

During measurements vibrations of the turbine tower in three axes were measured. In general there are no significant differences between signals measured in the vertical (y-axis) or horizontal (x- and z-axes) directions, neither in the time, nor in the frequency domains. However, there are small differences in the results gathered by the STFT method (examples are presented in Figs. 7 and 8). In Fig. 7 (turbine 2), we recognize stronger acoustic structures in the y- and z-axes as it is the case for the x-axes. Similar phenomenon can be recognized also in Fig. 10 (determined with the MUSIC method), where we can see two additional extrema for frequencies 4 and 6 kHz.

Analyzing the STFT results for turbine 5 (example in Fig. 8) we can recognize similar structures for all three axes, but the MUSIC method (example in Fig. 10) depicts that the frequency components in range 4–6 kHz are of higher energy in the signals measured for the x-axis.

There is also to state that in general the turbine 5 indicates frequency components of higher energy as it is the case for turbine 2. Assuming similar wind conditions during both measuring days, we can also state that the turbine 5 during operation generates vibrations of values mostly smaller than 2 m/s^2, and in the z-axis smaller than 1 m/s^2, while the turbine 2 during operation does not generate so many vibrations and only in situations when the wind is stronger, it generates vibrations, which do not exceed value of 5 m/s^2.

In further research studies we aim to perform also the electrical measurements and analyze differences between the two turbines during operation.

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