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Towards the use of secondary windscreens to improve wind turbine sound measurements

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Abstract

One of the major challenges for acoustic measurements nearby wind turbines is a sufficiently high signal-to-noise ratio between wind turbine and background noise. In the low frequency bands, the background noise is characterized by wind-induced noise at the microphone, which are caused by inflow turbulences. Those turbulences and hence, the wind-induced noise can be reduced by windscreens. In this contribution, four windscreen configurations are analysed regarding their influence on the acoustic properties and their potential of excess noise reduction. Hereby, a standard primary windscreen and secondary windscreens with different diameters and amount of layers are used.

The measured insertion loss increase with higher frequencies and with the amount of windscreen layers. Hence, the acoustic properties are most strongly affected by the windscreen with a triple layer. In the relevant low-frequency bands, all windscreen configurations have a small influence on the acoustic properties. Results of a field test nearby a wind turbine show that at 7 m/s the excess noise dominates octave bands below 125 Hz and covers the turbine noise using only a primary windscreen. This excess noise can be reduced by up to 10 dB using secondary windscreens so that the wind turbine noise is detectable. Considering only the field test, the windscreen with a triple layer has the biggest potential to reduce the wind-induced noise at microphones.

Keywords: Wind turbine noise, acoustic measurements, experimental setup, sound propagation

1 Introduction

Due to many circumstances, measurements in the field and near to wind turbines are challenging. Even before the actual measurement begins, a suitable measurement location with low extraneous noise (e.g. from traffic or agriculture) has to be found. In addition, agreements have to be made with operators and landowners, whose help is needed for successful measurements over long distances and over a long period of time.

From a technical point of view, the acoustical investigation of a complex source in the open field, under undefined measurement conditions, and partly under strong wind conditions is difficult. High wind speeds are necessary in order to achieve a high sound power level of the wind turbine. At the same time, however, this leads to additional sources such as wind-induced noises at the microphone or wind-induced noise from vegetation. The greatest challenge for acoustic measurements in the surrounding area of wind turbines is therefore a sufficiently high signal-to-noise ratio (SNR) between wind turbine and background noise. It is hard to get a high SNR due to the fact that the wind turbine sound and the background noise increase with higher wind speeds. The background noise is characterized by noise from leaves and vegetation in general as well as by wind-induced noise on microphones. Hence, acoustic measurement stations need to be placed as far as possible but at least 10m away from trees. To minimize the influence of wind-induced noise on the microphone, a standard windscreen and a specific developed secondary windscreens is necessary reducing the atmospheric turbulence incident on the microphone.

The focus of this work is on the reduction of wind-induced noise at the microphone by using secondary windscreens. The phenomena of wind-induces noise at microphones is explained and known solutions to reduce such an excess noise, i.e. secondary windscreens, are discussed shortly. The effectiveness against background noise and the acoustic properties is directly influenced by the used materials, the construction and the geometry of secondary windscreens. Hence, on the basis of measurements, various self-developed secondary windscreens are compared with regard to their acoustic properties and their reduction of excess noise. The efficiency of such a windscreen is demonstrated with field tests.

2 Phenomenon of wind-induced noise and its prevention

Since both the wind turbine noise and the wind-induced noise at the microphone are dominant in the low frequency range, it is difficult to separate the sources and thus identify the turbine noise. The main noise sources at a microphone with a primary windscreen are shown in Fig. 1. The inflow turbulence of an air flow and the resulting pressure fluctuations at a microphone are considered to be the main cause of excess noise when measuring in a windy environment. Further sources can be the flow through pores and self-induced turbulences, which are generated by the windscreen itself on the side facing away from the wind. However, those and environmental noises are classified as secondary sources.[3]

A primary windscreen, as used in Fig. 1, is considered to be a standard component for free-field acoustic measurements. At high wind speeds, this windscreen is not sufficient to reduce pressure fluctuations at the microphone. As a result, measurements on wind turbines require additional methods to improve the SNR. For near field measurements, the boundary effect is often used to achieve a 6 dB SNR improvement.[1] In addition, signal processing methods can also be applied in the data processing to artificially improve the data quality. A very effective and commonly used way to increase SNR is to further reduce the wind noise at the microphone with secondary windscreens. In Fig. 2, the basic functionality of a secondary windscreen is illustrated. The secondary windscreen completely surrounds the measurement microphone with the primary windscreen. It acts as the first barrier against wind and reduces the speed of the air molecules passing through it. This creates a space between the two windscreens with a slower, less turbulent flow than outside the secondary windscreen. As a consequence, less pressure fluctuations occur on the primary windscreen and hence on the measurement microphone. A detailed documentation on the state of the art of secondary windscreens is provided in Boas[2].

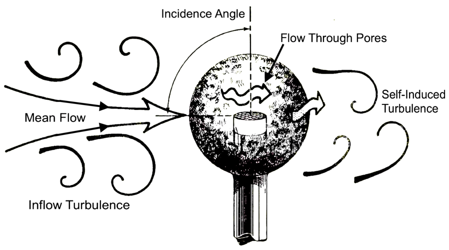

Figure 1: Noise sources on a windscreen, based on [3]

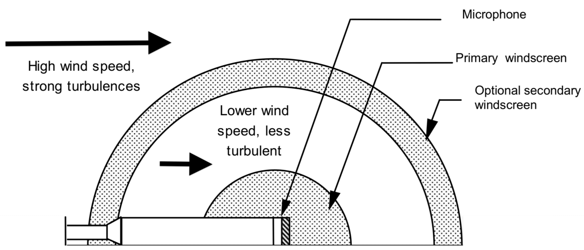

Figure 2: Schematic illustration of a secondary windscreen, based on [1]

3 Comparison of secondary windscreens

The secondary windscreens in this article were developed and constructed especially for the sound level meter 01*dB Duo* of the company *Acoem* and are connected with its primary windscreen. The support structure is a mesh grid with a tight fit for the primary windscreen, so that no special fixing is necessary. It is covered with acoustically permeable material. In the investigations of this work, windscreens were spanned with PA loudspeaker material. A detailed description of the construction steps and other materials tested are given in Boas[2]. The geometry of the windscreens was varied by the use of two diameters. In addition, a combination of both diameters was used creating a triple barrier to reduce wind-induced

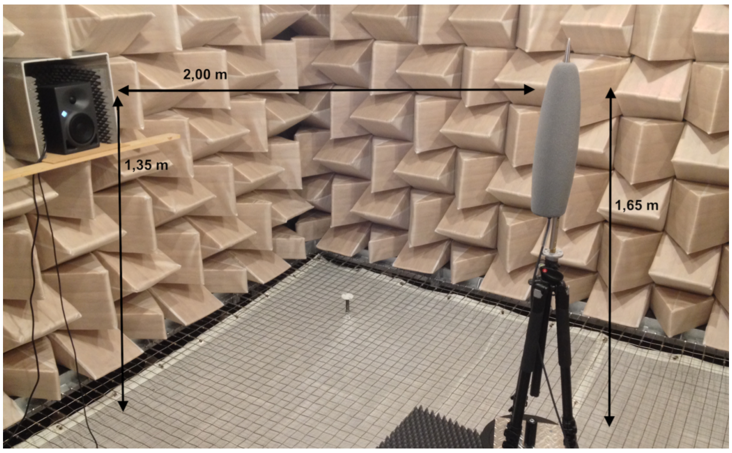

Figure 3: Measurement setup using the example of the primary windscreen

noise. Note that secondary windscreens are always to be used in conjunction with a primary windscreen. The variations of windscreens are summarized in Tab. 1.

Table 1: Variations of windscreens

Description	Diameter [mm]	Layers
PRI	110	one
SEC1	110	two
SEC2	220	two
TRI	110, 220	three

3.1 Acoustic properties

Placing a windscreen between the sound source and the receiver can change acoustic properties such as sound levels, frequency spectra and directional characteristics. This work includes the determination of the insertion loss to evaluate the level and frequency band change. As shown in Boas[2], the directivity pattern is not changed by the use of secondary windscreens. Measuring the insertion loss is not only important for analysing the windscreens, but also necessary for determining correction terms for the later application in the free field. In this contribution, the measurements were based on IEC 61400-11 and were performed in the anechoic room of the Institute of Communication Technology at Leibniz University Hannover. In Fig. 3 an example of the measurement setup is shown.

For one minute, pink noise was generated with the loudspeaker. The level without windscreen was about 70dB, so that the test signal is clearly above the background noise (35dB). For the 1-minute signal, the equivalent sound pressure level and 1/3 octave bands were determined. The following measurements were firstly performed with a primary windscreen, and secondly with various secondary windscreens.

Insertion loss of the total sound level

The reduction of the measured unweighted sound pressure level of all windscreens is shown in Fig. 4. The different combinations of diameter and covering layers have different insertion losses. With an insertion loss of 0.3 dB, the secondary windscreen with a diamater of 220 mm shows the smallest influence on the sound pressure level. In comparison, with the small diameter (110 mm), an attenuation of 0.4 dB is measured. In this case, the insertion loss increases with smaller diameters. The measured insertion loss with a triple layer (TRI) is 0.5 dB. Consequently this screen configuration has the biggest influence on sound pressure level.

Insertion loss by 1/3 octave bands

To obtain information about the insertion loss in certain frequency ranges the 1/3 octave spectra of the different windscreens are compared with each other (see Fig. 5). Since the loudspeaker covers a frequency range from 52 Hz to 21 kHz, frequencies below 50 Hz can not be reproduced correctly and are therefore not discussed.

In octave bands below 1.6 kHz, the insertion loss of all windscreens has a maximum of 0.4 dB. It increases with higher frequencies and is clearly seen in the medium to high-frequency range above 2 kHz. At high frequencies of 10 kHz values of 0.7dB were measured with the SEC2-windscreen, which is by far the smallest attenuation of the sound pressure level. At high frequencies, a much higher attenuation is seen with the SEC1- and TRI-windscreens. Using the TRI-windscreen, the maximum attenuation is approximately 2.5 dB at 20 kHz. Based on this measurements correction values are determined using the differences from the measurements without windscreens. This correction terms compensate the insertion loss caused by the secondary windscreens and are applied in free field measurements.

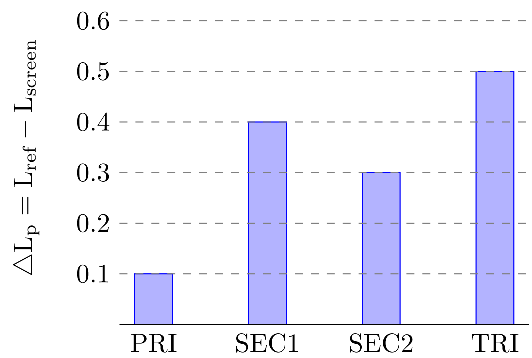

Figure 4: Insertion loss of sound pressure level

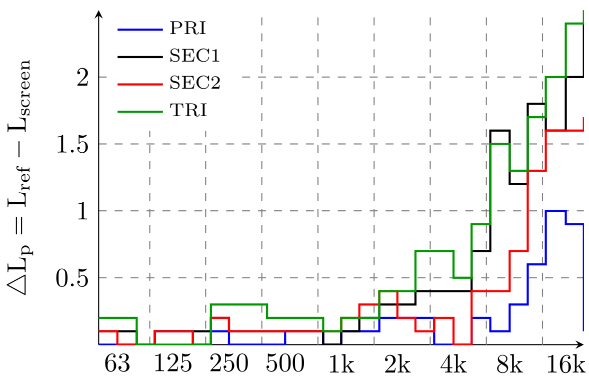

Figure 5: Insertion loss by 1/3 octave bands

3.2 Reduction of wind-induced noise

In principle, the laboratory test for noise reduction was similar to the measurement setup of insertion loss in the anechoic chamber. In addition, a fan was used which generated an average wind speed of 3.9 m/s at maximum speed. The test setup is shown in Fig. 6. For the different windscreen configurations, the 1/3 octave spectra were measured under the switched-on fan (wind) without pink noise. The values were then corrected by the corresponding insertion losses. The air flow of the fan generated the wind-induced noise at the microphone described in section 2.

The measured spectra of the test under windy conditions are shown in Fig. 7. Here no other sources than the fan, which has tonal components between 25 and 250 Hz, should be recorded. With the primary windscreen, pseudo sound levels of over 80 dB were measured in the low-frequency bands. With all secondary windscreens, this noise level was drastically reduced. Up to a frequency band of 500 Hz, compared to the primary screen, the wind-induced noise was reduced by at least 10 dB with the secondary windscreens. At 100 Hz, the reduction is more than 20 dB. As a results, the tonal components of the fans motor noise can be identified in Fig. 7. The greatest effect against noise was achieved by the windscreen with a diameter of 220 mm. As already described in literature, windscreens with larger diameters have a higher noise reduction in the low-frequency range. The results of the windscreen with a triple layer only differ at 63 Hz by 6 dB. This might be due to the fact that the second structure mounted on SEC1 was not stable enough and generated additional noise in this frequency band. In the laboratory test, the wind noise was not further reduced by the triple barrier compared to a double barrier.

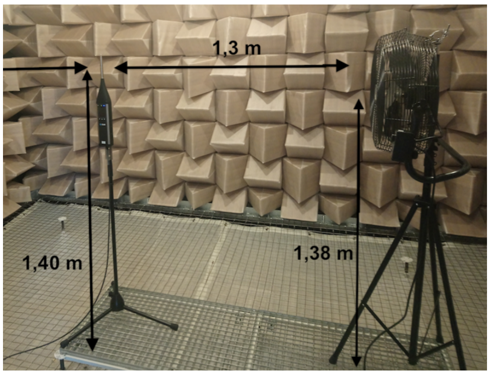

Figure 6: Measurement setup with fan

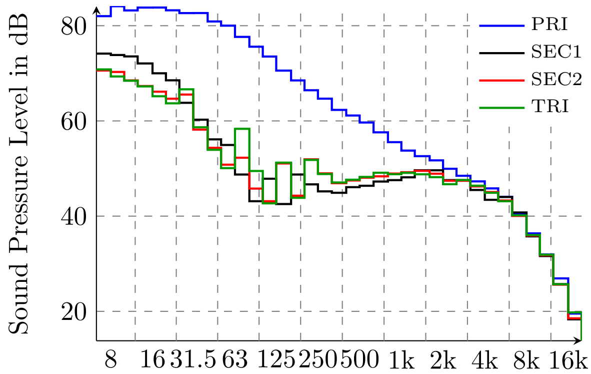

Figure 7: 1/3 octave bands under windy conditions

4 Field test nearby wind turbines

Due to the good performance in the laboratory, the windscreen with a diameter of 220mm as well as the screen with a triple layer were chosen for a field test nearby a wind turbine. As seen in Fig. 8, three sound levels meters were each fitted with windscreen configurations. As before, the results with the primary windscreen are used as reference. The sound level meters were placed in about 20 m distance to a 3.2 MW wind turbine and were fixed at a height of 1.70 m. Octav bands, sound pressure levels and audio were recorded for 3 hours of measurement time. Parameter describing the wind turbine conditions, such as rotational speed and wind speed at hub height were detected at the same time. To analyse the wind-induced noise and its reduction using secondary windscreens, acoustic and wind turbine data were averaged over 10 minutes and clustered in wind speed bins. Moreover, the acoustic data were corrected with the inversion loss determined by the tests in section 3.1.

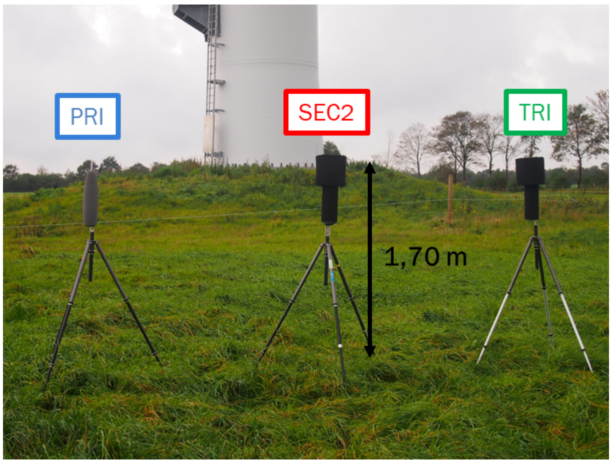

Figure 8: Measurement setup of the field test

In Fig. 9, averaged unweighted sound pressure levels are shown for the tested windscreen configurations and for wind speed bins of 3 to 7 m/s. Note, that the wind speed was measured at the hub height of the wind turbine, i.e. 93 m. The cut-in wind speed of the wind turbine is about 4 m/s. Consequently, the wind turbine was off for the bins 3 and 4 m/s so that no sound was emitted from the turbine. The values at 3 and 4 m/s represent the background noise accordingly. Even at these comparatively low speeds, the wind noise was reduced by 4 dB by the secondary windscreen SEC2. A even better result was achieved with the triple layer. Higher overall levels were measured with increasing wind speeds and thus increasing rotor speed. This is a known phenomena of wind turbine noise and is explained in Martens et al.[4] As can be seen at the differences between the primary and double layered windscreen in Fig. 9, the wind-induced noise at the microphone increased with increasing wind speeds. At 7 m/s the secondary windscreens reduce noise by up to 7 dB. The windscreen with a triple layer reduced the wind-induces noise at 7 m/s by 9 dB.

The detailed investigation of wind noise is performed using the 1/3 octave bands at wind speed bins 3 and 7 m/s (see Fig. 10 and 11). This implies that recordings with the turbine switched off, e.g. with pure background noise, and recordings with the turbine switched on, e.g. with turbine noise and background noise, are analysed.

At 3 m/s, the wind-induced noise at the microphone is dominant in the octave bands 8 to 31 Hz with the primary windscreen. At those frequency bands, the secondary windscreens reduce wind noise by up to 7 dB. Again, the triple-barrier windscreen is slightly more effective. Starting at 63 Hz, all windscreen configurations record a similar level that represents the original background noise.

At 7m/s, below 125 Hz, the wind noise at the microphone dominates when the primary windscreen is used (see Fig. 11). As a result, the wind-induced noise covers the wind turbine noise. Secondary windscreens attenuate the wind-induced noise by up to 10 dB. Here, the triple-layer windscreen also shows a higher attenuation than the double-layer windscreen. The difference is 1-2 dB. This could be caused by a further reduction of wind-induced noise, but measurement uncertainties can also contribute to the difference. Starting at 125 Hz, all windscreen configurations record a similar level that represents the wind turbine noise.

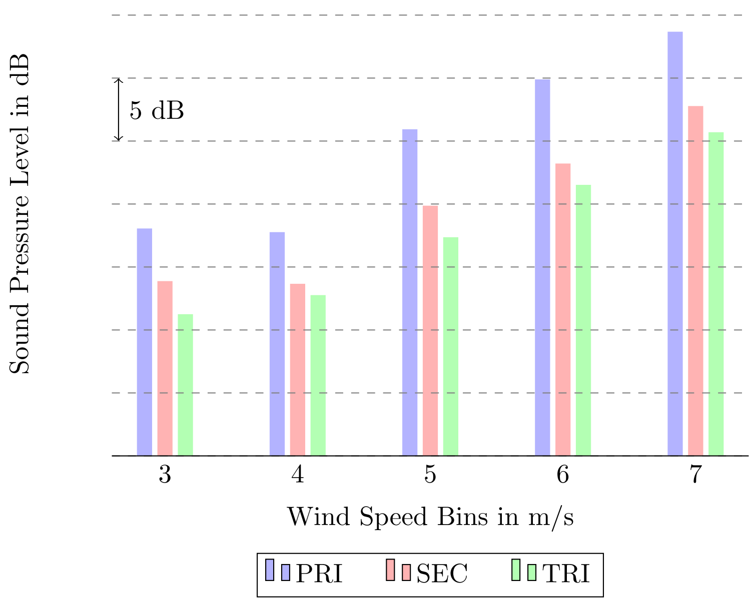

Figure 9: Measured unweighted sound pressure levels per ten minute at different wind speed bins

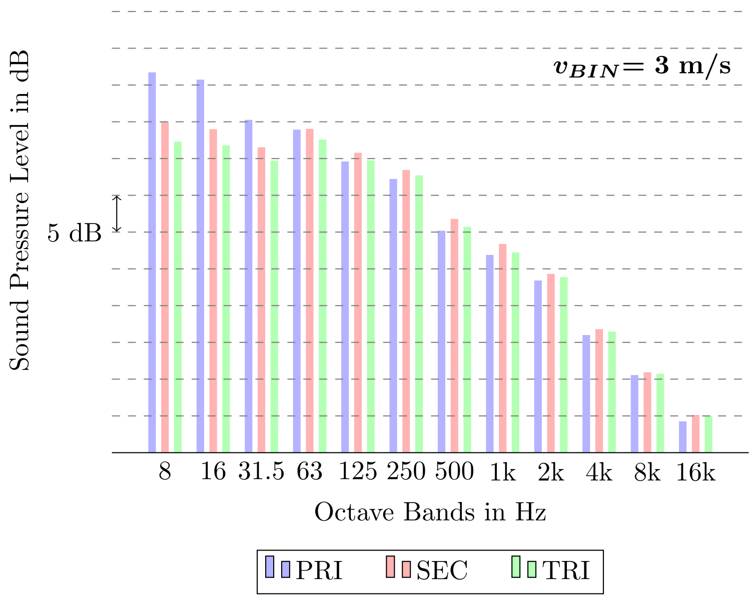

Figure 10: Measured unweighted octave band per ten minute at v_{BIN}=3 m/s

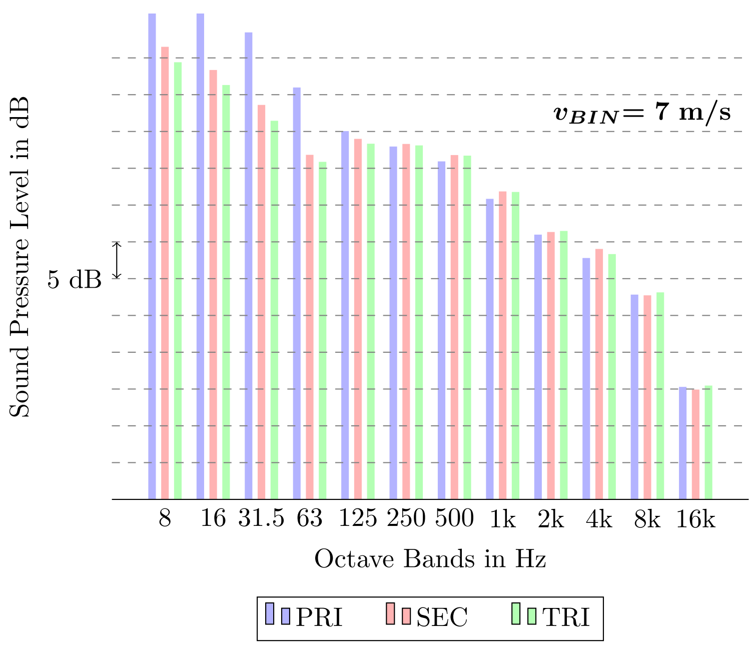

Figure 11: Measured unweighted octave band per ten minute at v_{BIN}=7 m/s

5 Conclusion and Outlook

Wind-induced noise at the microphone is dominant in the low frequency range and can effectively be reduced by secondary windscreens. All tested windscreen configurations had only a small influence on the acoustic properties. Due to the amount of layers, the windscreen with three barriers affected the those properties most strongly. At 20 kHz, the measured insertion loss was about 2.5 dB. But at the relevant low frequencies, the sound was only attenuated by maximum 0.4 dB. However, with the help of experimental determined correction values, the insertion loss caused by the secondary windscreens can be compensated. Using a fan as a wind source, all windscreen configurations effectively have reduced the wind-induced noise at the microphone in the laboratory. In general, windscreens with larger diameters have achieved a higher noise reduction in the low-frequency range.

A field test nearby a wind turbine was performed to analyse the reduction potential of windscreens with different amounts of layers. Generally, the measured sound pressure level increased with higher wind speeds and hence, rotational speed. At the same time, the wind-induced noise at the microphone increased due to the increase of inflow turbulences. With higher wind speeds, the wind-induced noise affected a wider frequency range. At 3 m/s, the wind-induced noise at the microphone was dominant in the octave bands 8 to 31 Hz. At 7 m/s, octave bands below 125 Hz were affected by the wind noise. At this wind speed, the wind turbine was running in partial load. Using only the primary windscreen, the wind turbine noise was covered by the wind-induced noise. By the use of secondary screens, the excess noise was reduced by up to 10 dB and thus the turbine noise was detectable.

Considering only the field test, the wind screen with a triple layer has the biggest potential reducing wind-induced noise at microphones. At the same time, this configuration has the most strongly influence on the acoustic properties. Measurements at higher wind speeds and accordingly at rated load of a wind turbine are necessary to finally assess the noise reduction potential of windscreens. These measurements will be performed and evaluated in the future.

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