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Reduction of tonalities in wind turbines by means of active vibration absorbers

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Summary

Despite careful design of wind turbines, unwanted tonalities can occur during operation. An “Active Damping Device (ADD)” is developed, which can be retrofitted and used to reduce vibrations in wind turbines. This way the disturbing tonalities are diminished and the legal or contractually defined limit of sound emission can be met. Taking measurements and FE-simulations are necessary for dimensioning the actuators, sensors and controller, and also for the development of a technology prototype, which has proven its functionality in field tests and enabled to initiate the product development process.

1. Introduction

When considering wind turbines in relation to noise, tonal components are critical, since they cause a particular disturbance for the hearing impression. This fact is supported by the assignment of tonality surcharges in the assessment of noise emissions according to IEC 61400-11 [1] and national counterparts. Despite careful design of the wind turbine, unwanted tonalities can still occur during operation. Their removal can be very complex, especially if a speed dependency of the tonalities is present.

Tonalities have their origin in the gearbox of a wind turbine. The meshing forces of one or several gear stages vary periodically with the respective meshing frequency. This constitutes a dynamic vibration excitation in the audible frequency range, mostly from approx. 80 Hz up to several hundreds of Hertz. As a consequence to this excitation, the gearbox reacts with vibrations in the excitation frequency. The gearbox vibrations are then transferred into the wind turbine and spread up to the rotor blades and the tower. During this transfer, they might be further increased by part resonances. In many cases, common gearbox supports cannot reduce the vibrations sufficiently, because the cutoff frequency of the isolation cannot be set low enough.

With their huge surface, the tower and the rotor blades transform the mechanical vibrational energy into acoustic energy and emit this energy as audible sound.

The acoustic quality of wind turbines is evaluated on the basis of the sound power level, which is to be determined according to IEC 61400-11. The noise of a turbine is mainly caused by air flowing around the rotor blades. This leads to audible broadband noise consisting of many frequencies, none of which stands out particularly. If gearbox tonalities occur, a noise with a fixed frequency, i.e. a tone, mixes with this broadband noise. It is known from psycho-acoustics that tonal noises (tonalities) are particularly unpleasant for people; therefore, the standards assign a so-called tonality surcharge to the determined broadband sound power level for tonal components, which can be up to +6 dB. With this surcharge, the authorized limits for noise emissions or the contractually agreed noise levels are often exceeded.

One possibility to reduce the sound of wind turbines is to prevent the propagation of gearbox vibrations - especially in the direction of the tower. This is achieved by compensating the present vibrations by a precisely applied counter-vibration before they can spread. For tonalities with fixed frequencies this can be realized with tuned mass absorbers, which are built up as spring-mass systems. These systems are adjusted to the tonality frequency and countervail the vibrations.
Another approach to mitigate emerging tonalities is the use of distributed active vibration absorbers. By means of appropriate control strategies and suitable positioning of absorbers and sensors, the entire speed range of the turbine can be addressed and reduction of sound at several frequencies is achieved.

2. Measurements and FE-simulation

Positioning the absorbers requires knowledge of the sound radiating components. This can be determined by structure-borne and airborne sound measurements in combination with finite-element-simulations of the system.
Initially the wind turbine is analysed via measurements and subsequently FE-Simulations are used to find the best positions of the active absorbers and to compare their efficiency with passive absorbers efficiency.

2.1. Measurements of structure- and air-borne sound

The structure-borne sound is obtained with acceleration sensors which are placed on specific components of the wind turbine at several measurement points. The velocity of vibration is measured over the entire speed range. Measuring points are located at the rotating and the stationary part of the wind turbine. Typical measurement curves are shown in figure 2.1 at a position of the rotating part.

The sound energy is recorded behind the wind turbine at the reference point. The distance between this point and the axis of the tower is equal to the maximal height of the turbine. The results show a significant increase over the entire speed range of the turbine: the frequency of the emitted sound follows the order of the rotational frequency, see figure 2.2.The same speed dependency of the maximal vibration level can be seen in the measurement data.

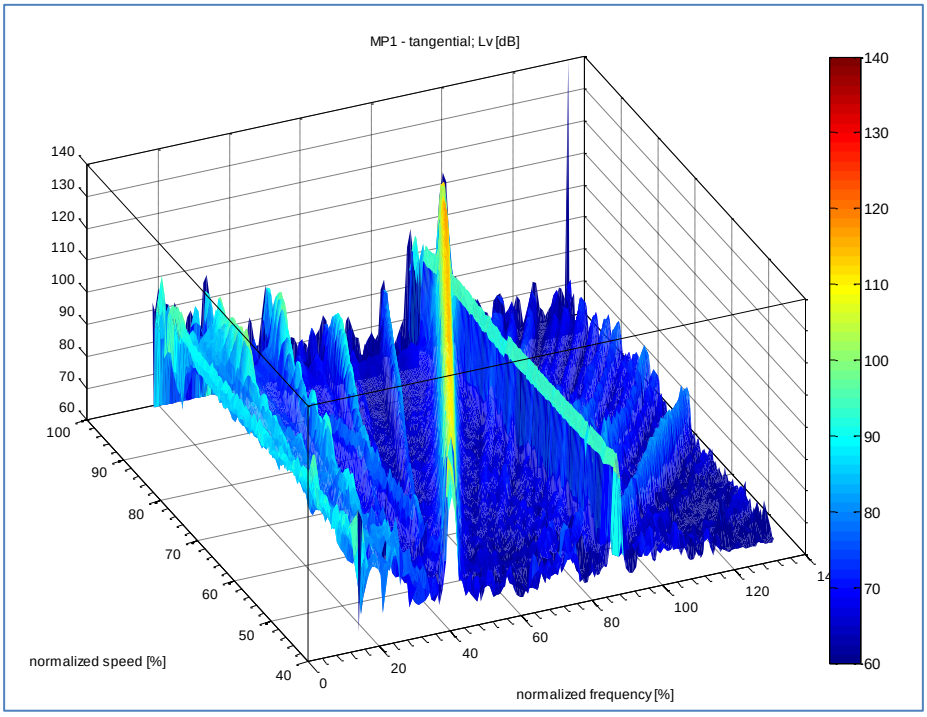

Figure 2.1 Exemplary presentation of vibration measurements

Since the sound measurements are not sufficient to find the components which cause the highest sound pressure level, it is required to identify these components via FE-simulations.

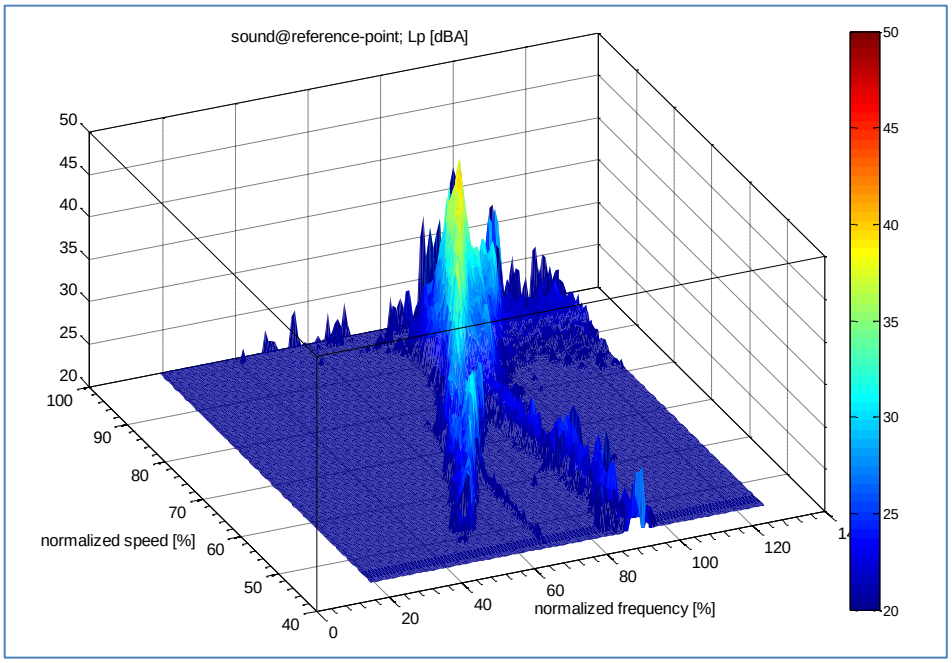

Figure 2.2 Measured sound pressure level at the reference point behind the wind turbine

2.2. FE-simulation (structure- and airborne noise)

FE-simulations are used to find the components which are emitting the largest part of sound pressure and how the audible tonalities are generated. Furthermore, two aspects are analysed: the actuator forces which are necessary to apply the countervailing vibrations and the optimal positioning of the absorbers to achieve the best efficiency. This information is the basis of developing a retrofittable solution to reduce sound emission of wind turbines.

With a structural dynamic model of the wind turbine (see figure 2.3 a.), first the structure-borne noise of potentially radiating components is calculated according to their material properties. Therefore the simulation of vibration is implemented using a defined excitation for each relevant direction of the turbine's drivetrain. The frequency range is equal to the measured one. By means of the measurement data, the vibration response is calibrated via superposition and scaling the simulation results. For selected points the results of measurement and simulation are compared, to evaluate if a sufficient concordance is achieved.

The calculated structure-borne noise is transferred to an appropriate airborne noise model. This transfer is carried out sequentially for each part of the wind turbine: blades, nacelle, hub and tower. The sound pressure is distributed over several layers behind the wind turbine. By a subsequent extrapolation of these results to the reference point (see figure 2.3 b.), the respective contribution of each component to the tonality level can be determined.

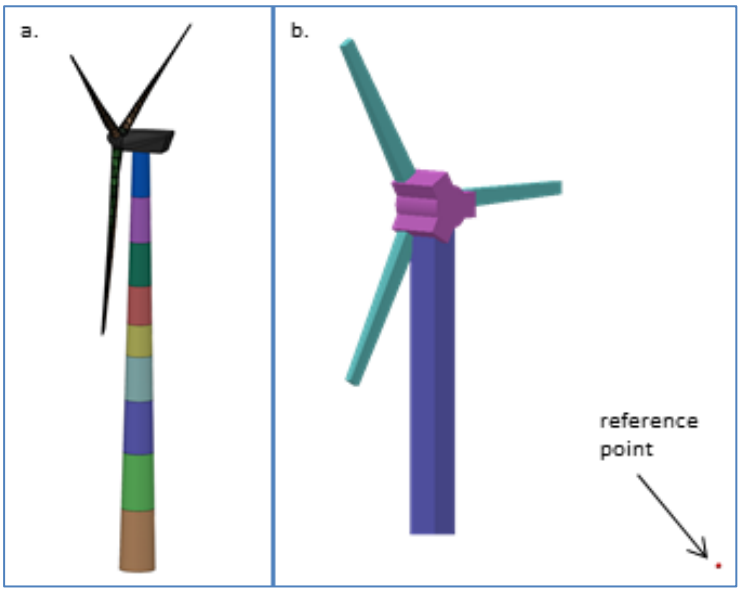

Figure 2.3 a. FE-Model to calculate the structure-born sound
b. FE-Model for airborne sound

The simulation results show that in this case the highest sound pressure level is achieved by the rotor blades, which means a difference of 5 to 25 dB in comparison to the other components of the wind turbine, see figure 2.4.
The next step is the integration of active vibration absorbers into the simulation model to determine the power requirements and the optimal placement of the absorbers. Therefore, the active absorbers are mounted in several combinations onto the rotating and the stationary part of the wind turbine in order to analyze their

respective efficiency and the required dynamic forces. For each actuator a power demand of about 3 kN is determined. The use of passive absorbers is not reasonable because of the pronounced speed dependency of the tonalities.

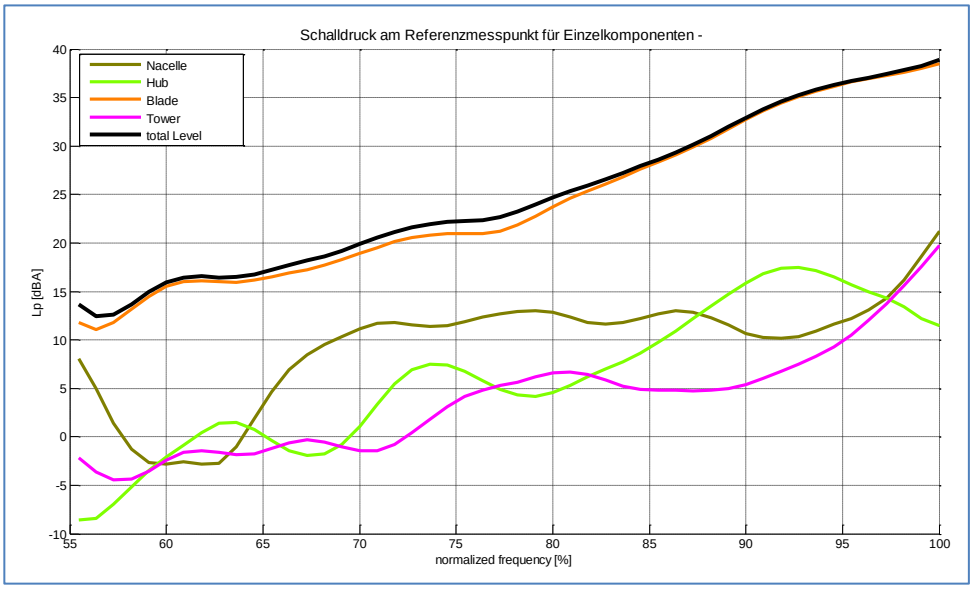

Figure 2.4 Comparison of sound radiation of the different components of the wind turbine

A comparison of the calculated sound level with and without absorbers, as shown in figure 2.5, allows an assessment of the achievable noise reduction. Field tests have confirmed the predicted reduction and the development of the retrofittable absorber ADD.Sound® as a standard product can be initiated.

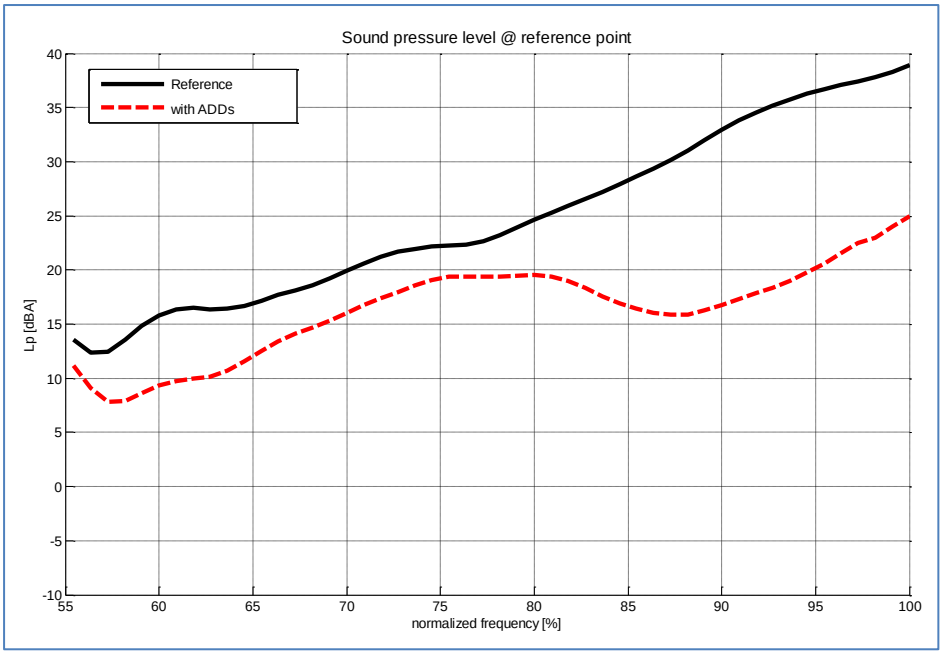

Figure 2.5 Comparison of sound pressure level with and without active absorber

3. Results of field tests

Field tests are performed with absorber prototypes which have a system mass of approximately 110 kg and a dynamic power range of up to 5 kN. Symmetrically positioned, multiple absorbers can generate adequate counter-vibrations which are transferred into the wind turbine, decreasing vibrations and obtaining significant reduction in the emitted sound.

The functionality of the prototypes has been proven and the predicted values used for dimensioning the absorber were confirmed (see figure 3.1). Furthermore, optimization steps could be identified.

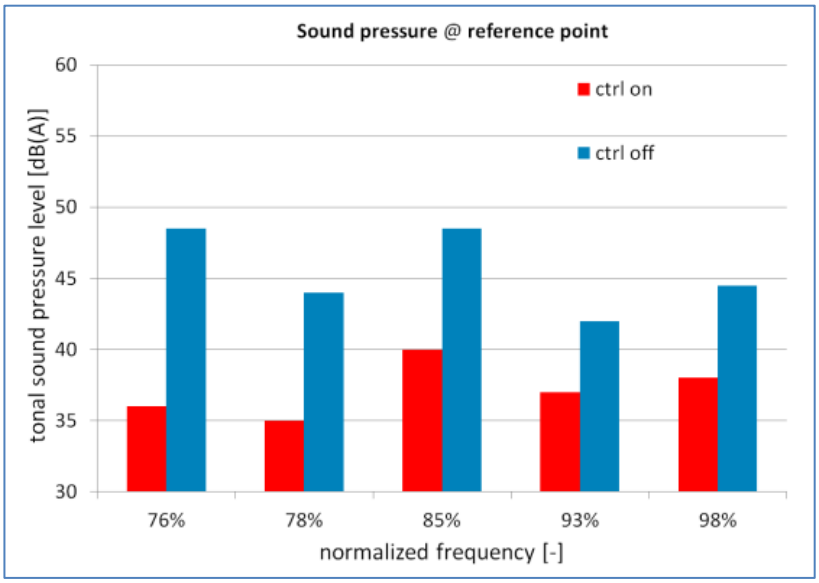

Figure 3.1 Comparison of sound pressure level at the reference point with installed ADD.Sound®, switched on and off

4. Design of Active Damping Device ADD.Sound®

An optimised design implementation of the active damping device (ADD) is based on the examination of the prototypes. This leads to hardware components and mounting techniques which are in compliance with the requirements of operational safety and cost efficiency.

The ADD consists of an actuator, sensor, electronics and a stationary frame which ensures the mechanical coupling to the wind turbine, see figure 4.1. The actuator is mounted on springs and consists of two electromagnetic drives. The total force of one ADD is in the range of approximately 4 to 5 kN with a system mass of about 110 kg.

To enable data evaluation and actuator control a decentralized line topology is implemented, whereby an easy assemblage of a variable number of ADDs is possible. A schematic illustration of the connection options is shown in figure 4.2.

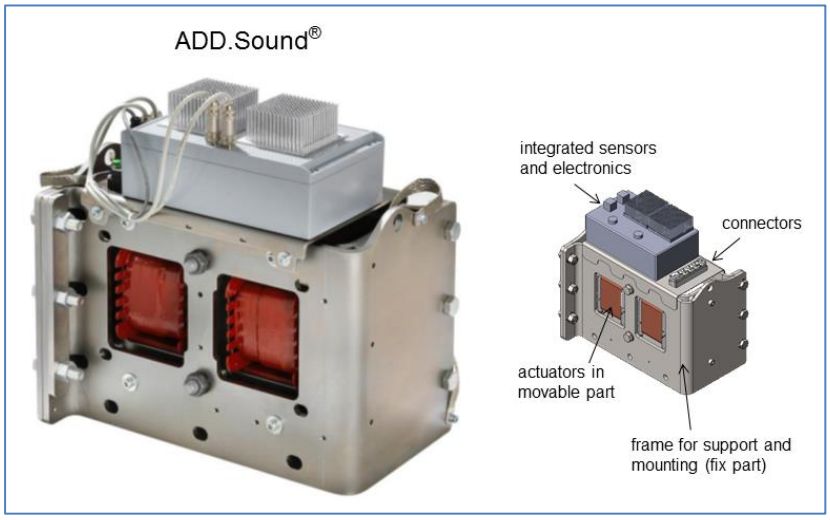

Figure 4.1 Photographic and schematic illustration of the components of the active absorber ADD.Sound®

An actively controlled absorber compensates several orders of tonal gearbox vibrations at variable speed over the entire speed range of the wind turbine, which is the main advantage over passive solutions. Compact dimensions of absorber and electronics are another advantage of the retrofittable ADD.Sound®.

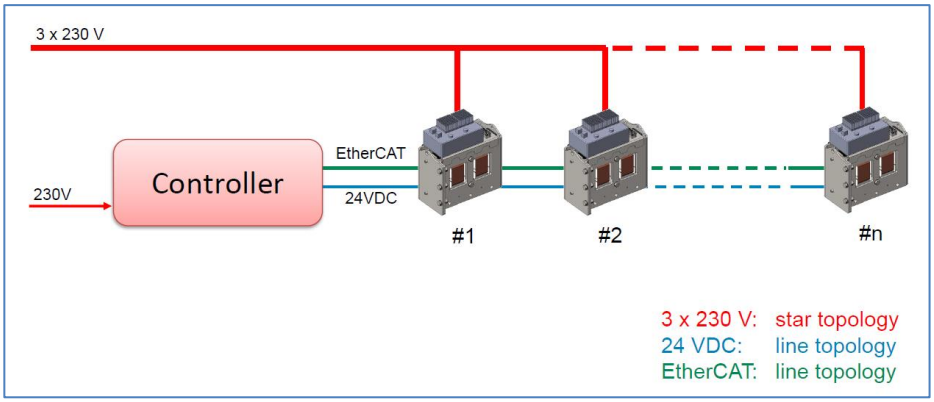

Figure 4.2 Schematic illustration of the connection options of multiple absorbers

5. Conclusion

The combined usage of measurements and simulations enables to identify the rotor blades as the component which causes the highest sound pressure level emission. To reduce vibrations of the wind turbine, active absorbers (ADD.Sound®) are installed and used to compensate several tonalities over the entire speed range.
With the introduction of ADD.Sound®, the sound emission of the wind turbine is significantly reduced and the legal requirements are met.

References

[1] IEC 61400-11:2012, Wind turbines – Part 11: Acoustic noise measurement techniques