Standards for the Assessment of Acoustic Emissions of Offshore Wind Farms

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Summary

Installation and operating of offshore wind turbines causes noise. Especially during the installation phase the hydro sound might exceed the threshold of “only disturbing” marine animals. Still neither a threshold for acoustic noise immissions nor standards for measurements and evaluations are defined. Based on measurements and in cooperation with biologists, recommendations for standard measurements and evaluations result from a research project financed by the German Ministry of Environment. Relevant parameters of structure-borne noise and hydro sound have been derived from basic studies of technical and physical aspects. Prediction methods for noise immissions during construction and operation of wind turbines have been worked out and have been compared with results of measurements.

Introduction

The above mentioned research project is about technical and physical aspects. Biologists need a standardised basis for the discussion of their aspects. Actually we face the problem, that there are certain dB – values discussed, but practically no one really knows what these values mean and how they can be measured.

By far the highest impact is expected in context of installation of offshore wind turbines. Available results of hydro sound measurements made during pile driving actions in Denmark have roused biologists, because sound pressure levels of more than 200 dB indicate a range where a temporary or even permanent threshold shift (TTS or PTS) has to be considered.

Noise during the installation phase and especially noise emission of pile driving will be a main part of the following text. Another item extracted from the research project is the prognosis of acoustic noise immission from operating offshore wind turbines based on transfer functions.

General Aspects

Concerning German offshore wind turbine projects, animals affected by the noise are: harbour porpoises, harbour seals, grey seals and also fish.

Depending on the rage of impact different zones can be defined in the surrounding of a source of acoustic noise. Far from a source of sound, the acoustic noise will be below the hearing threshold. Within the zone of audibility there is an area of reaction, where animals will show some kind of reaction. Closer to source of sound important acoustic information might be masked. Close to a very loud source of acoustic noise, animals might even get damaged. Even the lowest level of damage, which is a temporary threshold shift, must be avoided.

Acoustic Noise from Operating Offshore Wind Turbines

The following Figure illustrates the underwater noise radiation of a wind turbine.

![Fig. 2: Acoustic Noise from Operating Offshore Wind Turbines](image)

Information about the future noise immission prior to the installation of wind turbines can be derived from an Acoustic Noise Immission Prognosis.
Sound Pressure Levels around a Wind Farm (for example at 2 km)

Fig. 3. Determination of a Transfer Function

The excitation, e.g. vibration of gear or generator, causes structure borne noise in the wind turbine tower, which is radiated as underwater noise.

Fig. 4: Determination of a Transfer Function

The transfer function is the relation of sound pressure level and acceleration and is depending on the frequency. The transfer function can be calculated using a finite element calculation or can be measured via vibration and hydro noise measurement, as shown in the next figure.

Fig. 5: Prognosis of Sound Pressure Levels of a Hypothetical Multi Megawatt Wind Turbine and Measured Values for Different Wind Turbines

Noise during Construction of Offshore Wind Turbines

Pile driving noise has been measured during the construction of the FINO 1 research platform.

Fig. 7: Offshore Research Platform FINO 1

Fig. 8: Pile Driving FINO 1 (towboat, working platform, pile)

Fig. 9: Pile Driving FINO 1 (jacket, working platform, pile)
The acoustic noise has an impulsive character. The whole action took approximately 2 hours including some intermission with no intensive sound radiation. The work started with approx. 60 beats per minute and goes down to approx. 45 beats per minute at the end. Measurements presented here were performed at a distance of about 400 m from the pile.

The Equivalent Continuous Sound Pressure Level, a common parameter in acoustics, can be used for statistic purposes and to get an overview over the whole measurement time series.

**Equivalent Continuous Sound Pressure Level**

\[
L_{eq} = 10 \log \left( \frac{1}{T_0} \int_{0}^{T_0} \frac{P(t)^2}{P_0} dt \right)
\]

- \(P\): Sound Pressure
- \(T\): Time Interval
- \(P_0\): Reference Sound Pressure (hydro sound \(= 1 \, \mu Pa\))

In addition, biologists need information about the peak values of the immissions.

**Single Event Sound Pressure Level**

\[
L_E = 10 \log \left( \frac{1}{T_0} \int_{t_1}^{t_2} \frac{P(t)^2}{P_0^2} dt \right)
\]

- \(T_0 = 1\) Second

The Definition of \(L_E\) is same as for \(L_{eq}\), except of the standardisation to 1 s \((T_0)\). The time interval \(t_1\) - \(t_2\) must cover the whole impulse.

**remark:** Acoustic noise measurements sometimes use a value called “Sound Exposure Level” (SEL). The definition of the Sound Exposure Level (SEL) is the...
same as for $L_E$. But you should ensure, that only one impulse per time interval is regarded as “event”, when using the SEL function implemented in your noise level meter. The SEL value for some minutes of pile driving including $n$ pulses will be $10 \log n$ dB higher as $L_E$.

$L_E$ can be used for spectral analyses as shown in the next picture.

![Spectral Analysis](image)

**Fig. 16: Pile Driving of FINO 1 (1/3 Octave Band Spectra measured at 400m distance)**

### Recommended Standards for the Construction Phase (impulse pile driving)

Based on the performed measurements and including some preliminary results of the discussion with biologists, the following example of recommendations have been stated.

| Hydrophone position | 200 m – 1000 m from the pile  
|                     | Lower half of sea depth, > 5 m above sea flour |
| Time range          | Entire pile driving action |
| Frequency range     | 5 Hz to 20 kHz |
| Noise level overview| $L_{eq}$ (10s averages)  
|                     | $L_{peak}$ |
| 1/3 Octave band spectra | $L_E$ (max, min, typical) |
| Further parameters  | Duration of pile driving action  
|                     | Time interval $(t_2-t_1)$ for the determination of $L_E$  
|                     | Number of impulses per minute |

**Table 1: Example of Recommended Standards for the Construction Phase for Impulse Pile Driving**

Today the basis in the discussion with biologists is an immission limit value of 160 dB at 750 m. This value has been derived from audiograms of harbour porpoises. We need noise reduction efforts to keep this limit.

**Conclusion**

For a serious discussion with biologists and authorities aiming at steps to avoid damage of marine animals, reliable data of the expected noise emission during the installation of large offshore wind turbines are needed. The authors have performed hydro sound measurements during the pile driving of the platform FINO 1 in the north sea and another platform in the east sea. Requirements for measurements and evaluations have been worked out. This standardisation is necessary, because the calculated critical distance from the same pile driving action may be easily two or four times higher, depending on the measurement configuration, the evaluation and the regarded parameter.

German authorities demand to keep certain noises reduction standards also for the operating phase of offshore wind turbines. During the above mentioned research project, measurement and evaluation standards as well as prediction methods for noise immissions during the construction and operation of wind turbines have been worked out.

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### References


