

Modelling the underwater noise associated to the construction and operation of offshore wind turbines

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Abstract – *The operation and in particular the construction of offshore wind converters induce considerable underwater noise emissions. It is assumed that small whales and seals can be affected by noise from machines and vessels, piling and installation of the wind turbines. Piling, in particular using hydraulic hammers creates impulsive noise with considerable high energy levels. Currently, only little knowledge about the effects of different noises to marine life is available. Here, we present an ongoing project from the Laboratory of Applied Bioacoustics (Technical University of Catalonia): to simulate the generation, radiation and propagation of underwater noise; to develop forecasting hydro sound models of offshore wind converters and future noise reduction methods during pile driving; to determine the impact area of offshore wind farms; to allow the formulation of recommendations for acoustic emission thresholds; and to develop standard procedures for the determination and assessment of noise emissions.*

Keywords – *Offshore wind farm, pile driving, underwater noise.*

INTRODUCTION

Control measurement campaigns have been conducted during construction of several wind farms in Europe, specially in Great Britain and Germany [1] [2], but the lack of accurate models on sound generation and propagation in shallow water scenarios and on the scientific evidence of the effects on marine life prevents a decided call for legislation being made on mitigation mechanisms, maximum levels, safety distances from specially sensitive areas, etc. We propose developing analytical and numerical models to assess the structural and environmental radiating noise directly produced by the construction and operation of wind turbines.

Pile Driving Noise.

Wind turbines are structures anchored to the sea bed with cylindrical steel piles. The exact supporting pile size depends on the wind turbine size and type. For a 2MW wind turbine (like Vestas V-80 type) the pile measures about four meters in diameter, weighs about 275 tones and is nailed to the sea bed a minimum of 25 meters underground.

The process of putting the pile in place is performed by means of vibration or impact hammers of very high energy. For instance the IHC S-600 hammer model, used in offshore pile driving, delivers an energy of 600 kNm (kJ) in each blow and at forty blows per minute rate. Needless

to say that each impact of these hydraulic hammers during the piling process is prone to produce a significant amount of acoustic energy that propagates into the marine environment and, as other high intensity sources, may severely affect marine organisms [3] [4].

To accurately predict this noise several phenomena must be taken into account:

- The impulsive sound that results from the impact.
- The ringing sound that results from the excited vibration modes of the structure.
- That the supporting pile is immersed in two dense mediums: part in water and part in the fluid-like sandy bottom which will affect the vibration modes.
- That suitable places for wind farms have water depths of about 20 meters or less. This constitutes a very specific scenario for sound propagation, known as shallow or very shallow waters.



Fig. 1 Pile driving process. [2]

Wind Farm Operation Noise.

The noise generated by the routine operation of the turbines is well studied in the case of onshore wind farms as it sometimes causes complaints from close by inhabitants. This noise is mainly produced by the turbulences caused by the movement of the blades (airborne) and secondarily by the mechanisms in the gear box (structureborne). But in the offshore case these noise sources will not directly induce any underwater noise since

the big difference between the impedances of the two mediums involved (air and water) favours the reflection of the sound back to the atmosphere and so prevents it from entering the water layer from this path.

The main way operation noise can enter the water is via the structural vibration of the supporting pile. This vibration will be of course related to the blades vibration and to the gear box operation, part of their vibratory energy being transmitted to the supporting pile that then induces sound pressure waves in the water.

To accurately predict this noise several considerations must be taken into account:

- The mechanical complexity and possible variability of the vibration inducers (blades and gear box) makes it too adventurous to try to predict their vibrations (amplitude, frequency content and velocity vectors) from a primary finite element analysis. Empirical measurements will be necessary.

- During operation the supporting pile will enter a continuous induced stationary vibratory state.

- The supporting pile is immersed in two dense mediums: part in water and part in the fluid-like sandy bottom. This will affect the vibration modes.

- Shallow or very shallow water constitutes an acoustic waveguide with its specific propagation modes, cut-off frequencies, modal dispersion and the like.

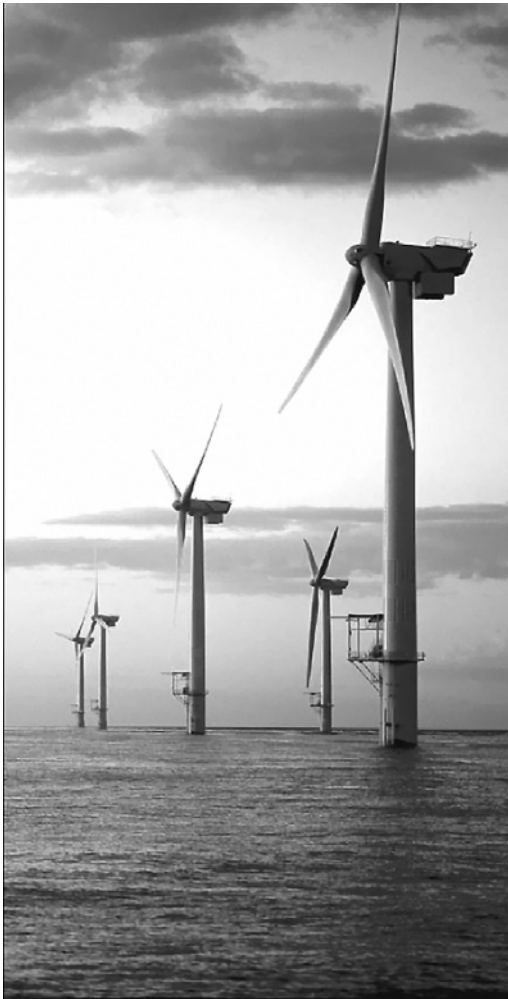


Fig. 2 Offshore wind farm in operation.

PILE DRIVING NOISE PREDICTION

The pile driving mechanism is conceptually basic and a complete analytical approach can be tried though it is not immediate.

The hammer impact can be viewed as the impact of two cylinders and the noise generated during the impact at the point of contact can be calculated from the impulsive acceleration of the structure walls.

A classical reference on impact noise is the series of articles from Richards [5].

Nevertheless this impact sound peak will be produced out of the water and although its analysis is necessary before going further in this study, its effects underwater will be presumably negligible since it will be strongly attenuated by reflection in the water interface.

Structural pressure waves will travel along the pile after the impact. Depending on the boundary conditions they will travel back to the impact point due to reflections even before the impact process is finished. These structural waves, essentially longitudinal will induce surface normal accelerations due to Poisson effect, by which a longitudinal wave induces motions transverse to the wave direction. Flexural wave types, although not possible in pure longitudinal force excitation are not discarded and its appearance must be investigated. Both types of waves can induce sound in the surrounding fluid media: air, water or sand and despite the successive reflections, the nature of the sound is expected to be impulsive due to the length of the pile and its structural losses and to the dispersive boundary conditions at the pile ends.

A good reference to understanding the impact induced structural deformation and vibration is the book by Goldsmith [6].

A frequency domain analysis is possible as well, by treating the impact of the hammer as an impulse excitation with certain frequency content depending on its duration and shape. Then the response of the system to this excitation can be calculated in frequency domain if the frequency response function of the cylindrical shell is known. This is a rather complicated matter and extensive literature is available. As early as 1973 Leissa [7] presented a review on shell vibration with up to ten different approaches to the problem and more than a thousand references.

In time domain or in frequency domain, the objective of the former analysis is to account for the surface normal acceleration of the cylindrical shell, needed for computing the sound pressure radiated as the last step in the problem.

WIND FARM OPERATION NOISE PREDICTION

Due to the complexity of the vibration mechanisms involved (rotating blades and gear box) neither an analytical prediction, nor a reliable finite element simulation can be made about the feeding forces of the system, thus a measurement based model seems compulsory in this case.

Depending on the measurement results and its frequency content a Modal approach or an energy (SEA, statistical energy analysis) approach of the problem will be preferred.

In this analysis care must be taken in properly considering the structural load that a dense medium like water (or water soaked sand) infringes on the structural vibration and on the efficiency by which these vibrations can radiate sound due to the phenomena of subsonic and supersonic structural waves in relation to the velocity of sound in the medium. The SEA approach is particularly suited if vibration/sound mitigation techniques are to be introduced in the simulation.

NUMERICAL SIMULATIONS

Clearly, the analytical approaches to the problem are intricate and up to this date full of uncertainties but nevertheless necessary to give insight into the physical mechanisms of vibration and sound emission and a necessary basis to scientifically demonstrate and explain the direct observations and the results from the numerical simulations to be made.

The structural vibration, in the piling process or in continuous operation, can be modelled using finite element methods (FEM), accounting for the fluid loading of the structure by the use of infinite finite elements or similar techniques. For the sound propagation, other methods like boundary element methods (BEM) can be better suited for the complex waveguide-like scenario of the shallow waters where wind farms are constructed. Simplification techniques like fast multipole expansion (FME) could be used if judged necessary.

Care must be taken that the algorithm properly treats the physical presence of the pile, which can't be approximated as a point source, at least in its vertical coordinate. All available propagation algorithms do work with point sources [8] and although raw superposition techniques can be used to deal with the problem a preferred and more elegant solution would be to develop specific formulas that take advantage of the cylindrical symmetry of the problem.

On the other hand and despite the technique, the algorithm must allow the estimation of the noise radiated from a hypothetical number of different elements (wind mills) in arbitrary positions and in a variety of environments in terms of water depth, bottom slope and composition, etc. In terms of sound levels, the last process is crucial to advise on the noise introduced in the environment and accordingly decide on the maximum number of elements that would compose a sustainable wind farm field.

MEASUREMENTS

In order to improve the models, to drive out uncertainties and to corroborate the predictions, a series of experimental measurements is planned. This will be done by carefully placing accelerometers and extensional gauges in the pile to measure vibrations and by placing hydrophones at different depths and distances to measure the radiated sound. As an example, the existence (or not) of flexional structural waves in the pile can be detected and differentiated from the longitudinal ones measuring the

dispersion along the pile with two accelerometers at different depths.

To confirm the shape and spectra of the emitted pulses is other obvious objective and data is already available in the published literature [2].

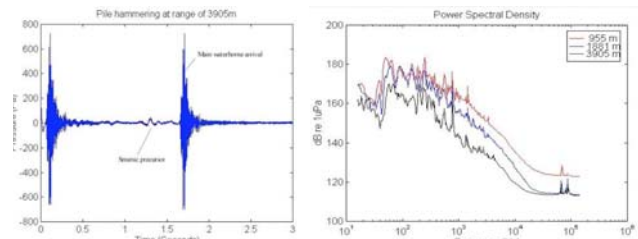


Fig. 3 Pile driving noise measurements. Reproduced from [2]

ENVIRONMENTAL EFFECTS

Both pile driving noise and operation noise are to be studied since both can have an effect on sea life. Pile driving noise is much more powerful and can do serious physical harm to some animals but is a transitory operation that lasts for some months during the wind farm construction and then stops. Wind farm continuous operation noise on the other hand is much lower but will be uninterrupted at the site for many years. It could affect the behaviour of some species, possibly altering the ecosystem equilibrium of the site.

Neither the impulsive nor the long term noise effects on marine life are clearly stated yet and although the negative effects clearly are accepted to exist, the boundary levels are not clear. This is a parallel research that in conjunction with the wind farm noise research will allow advice and recommendations to be given for acoustic emission thresholds and to determine the impact area of the offshore wind farms.

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