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ULTRASONIC TESTING OF OFFSHORE TURBINE STRUCTURES

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Motivation and objectives

Due to the growing number of offshore wind parks in the North Sea and the Baltic Sea, the demand for adapted and cost-efficient monitoring methods is rapidly increasing. Figure 1 shows the EnBW Baltic 1 wind park, the first commercially operated offshore wind park in the Baltic Sea.

The focus of wind farm monitoring lies on the foundations of the plants, which are permanently exposed to tidal, wave, and wind forces. The steel-concrete-steel connection (grouted joint) between the monopile, which is driven into the seafloor, and the transition piece, the access and service platform, is a central element in a monopile foundation. Figure 2 shows a service platform, which allows access to the turbine. Maintenance and inspection are performed from this transition piece.

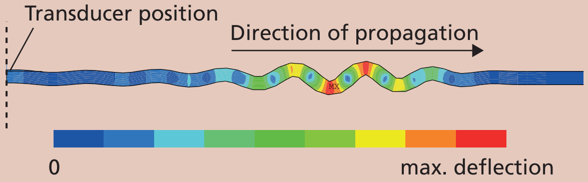
Methods for monitoring the concrete hardening process and for the detection of defects in the grouted joints are currently not available for offshore structures. However, techniques and acoustic methods known, e.g., from bridge construction can be used for monitoring the concrete hardening process and the concrete quality. The challenge lies in developing a sensor-actuator system for a test object with the size, structure, and geometry of a monopile foundation. Furthermore, access to the turbine, which is currently only possible via the transition piece (Figure 2), must be taken into account.

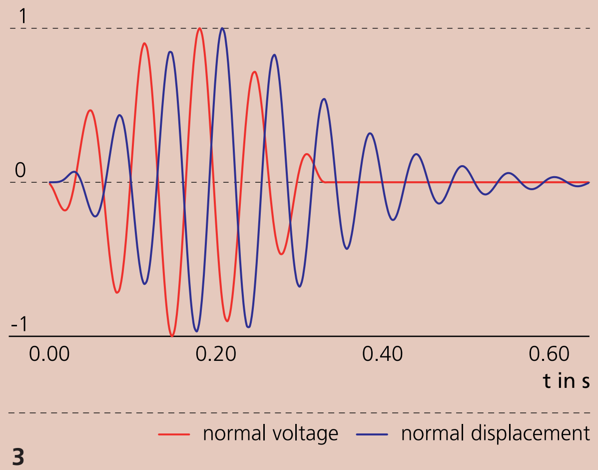
The first step was to develop the methods to be used as a basis for monitoring the grouted joints by guided waves. This was realized by simulations in order to estimate the frequency range from dispersion curves and determine the necessary acoustic power of the ultrasonic transducer based on an optimum receiving level. The accessibility in the turbine and the attenuation caused by the surrounding water and the seafloor were taken into account. The simulation results also yielded information regarding the minimum detectable size of defects in the concrete.

Transducer layout and design

The transducer layout focused on the dimensioning of the piezoelectric element, where the conversion from electrical excitation to mechanical wave took place, and on the acoustic wave transmission into the tested structure. In the present case, the latter was a thick sheet made of construction steel. Finite element (FE) analysis utilizing the FE package ANSYS was used with parametric models generated for this purpose. By varying the height of the piezoelectric element, the number of piezoelectric layers, and the geometry of the sonotrode, it was possible to develop a configuration with the maximized deflection at

Simulation of transducer radiation pattern





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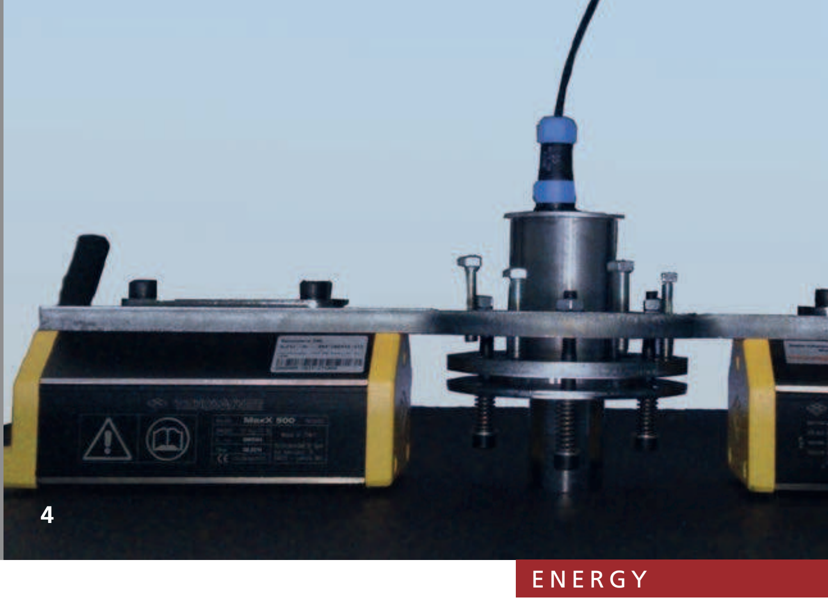

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the optimum rate of decay. The simulations showed that in transient operating mode, which is typical for acoustic structural monitoring, a backing brings no additional benefit. Furthermore, the optimum transducer height was found to depend on the geometry of the structure under consideration. The Figure on the left-hand side shows the axisymmetric FE model of the steel sheet with an induced bending wave. The transducer (not shown) is situated along the rotational axis on the sheet on the left side of the figure.

Figure 3 shows the electrical voltage and the resulting displacement at the bottom side of the steel sheet right below the transducer as a function of time. The distinct vibrational decay is indicative of a very clean and concentrated induced signal.

The simulation also takes into account the acoustic force over time inside the piezoelectric element as well as between the sonotrode and the sheet. From this information, the necessary preloads in the piezoelectric element and the required contact force of the transducer assembly were derived. The latter formed the basis for the design of the transducer support. Since permanent installation of supporting structures was not the desired solution for the present case, a magnetic mount with permanent magnets was developed. This had the main advantages of not requiring any additional power supply and being commercially available in various sizes in the form of lifting magnets. The actual transducer assembly consisted of a piezoelectric element and a sonotrode. It was mounted on a baseplate via a rotating pivot mount to enable flexible positioning of the transducer. An interchangeable sonotrode tip allowed for simple adaption of the sonotrode to different curvatures of the contact surface.

Experimental validation

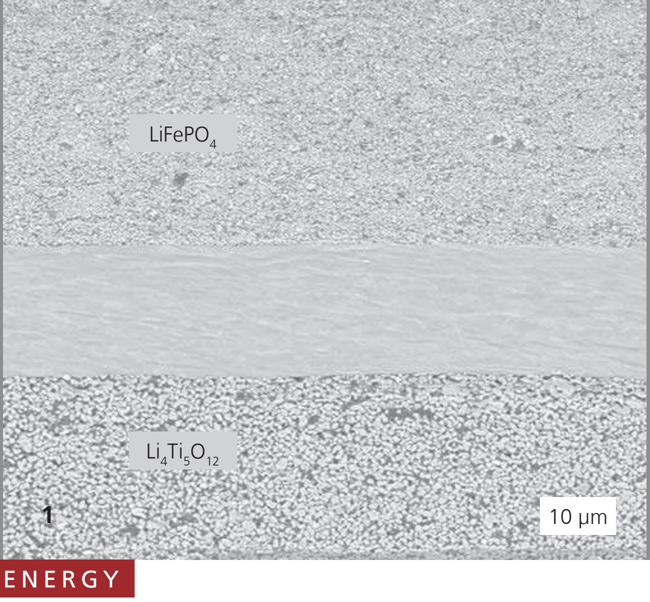
The transducer construction and the inspection technique were validated in laboratory experiments and onshore measurements. The simulation-based design of the actuator was successfully verified by 3D laser vibrometry. Figure 4 shows the laboratory setup. The emitted acoustic power corresponded to the simulation predictions. In a further step, it was possible to carry out acoustic measurements on an onshore monopile to confirm the feasibility. Offshore measurements will follow.

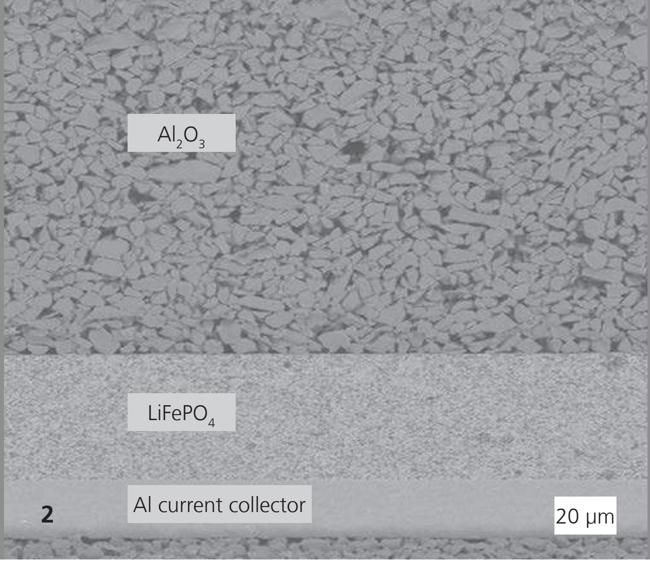
Summary

The monitoring and testing of offshore wind turbines imposes completely new demands on measurement equipment and the applied technologies. The developed ultrasound test equipment can be used for the monitoring of concrete hardening in grouted joints during the erection of wind turbines and for defect detection in these joints during operation.

With initial simulations using in-house simulation tools, design and layout of ultrasonic transducers, and test measurements, Fraunhofer IKTS offers a complete development chain for adapting existing structural monitoring techniques to customized and technically challenging applications or developing completely new techniques. The transducers specifically developed for the monitoring of grouted joints and the corresponding measurement equipment can be adapted to requirements of various applications. The offer also includes measurements for process development and validation performed by Fraunhofer IKTS.

1 *Baltic 1 offshore wind farm.*
2 *Transition piece in an offshore wind power plant.*
3 *Simulation of transducer radiation pattern.*
4 *Laboratory setup of a manufactured actuator for laser vibrometry measurements.*





EMBATT BIPOLAR BATTERY: NEW BATTERY DESIGN FOR HIGHER ENERGY DENSITY

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Availability of low-cost battery systems and energy densities higher than 450 Wh/L are prerequisites for wide-scale market penetration of electric vehicles. To meet these requirements, the established monopolar Li-ion cell technology employs active materials with increased energy densities or optimized cell and system packaging. With the EMBATT battery design, Fraunhofer IKTS and partners IAV GmbH and ThyssenKrupp System Engineering GmbH are taking a new approach. The consortium jointly develops large-scale lithium bipolar batteries as well as the associated manufacturing technologies and concepts for direct integration into vehicle chassis. The EMBATT bipolar battery consists of stacked cells, in which the current collector of the negative electrode of one cell is in contact with the positive electrode of the next cell. Thus, two electrochemical cells connected in series share one current collector – one side of the bipolar electrode serves as the anode in one cell and the other side as the cathode in the next cell.

Through this simple stacking of cells, the bipolar battery design does away with complex cell packaging and delivers a stack voltage resulting from the number of single cells in the stack. The advantages of this design are numerous: low internal resistance in the stack, the option to use very large electrode areas, and elimination of the need for extensive cell connections as are found in conventional battery systems. The EMBATT design thus transfers the high energy density from the cell level directly to the battery system.

In the first step of the recently started project, the partners developed a cell design optimized for subsequent manufacturing and vehicle integration. Fraunhofer IKTS developed the design of the bipolar electrode as well as suitable environmentally friendly and efficient production processes.

Based on the results of studies conducted to determine the optimal electrode balancing, bipolar electrodes were prepared with $Li_4Ti_5O_{12}$ (LTO) as the anode and $LiFePO_4$ (LFP) as the cathode material. Use of $LiNi_{0.5}Mn_{1.5}O_4$ (LNMO) on the cathode side in the future will allow for a further increase in the cell voltage and hence the energy density of the stack. Studies on the optimal synthesis conditions of this so-called high-voltage cathode material are currently underway.

Technologies aimed at simplifying future cell production by enabling a ceramic separator to be applied directly to the electrode are also being developed. This will eliminate the need for an additional separator component for the bipolar battery.

In initial tests, bipolar stacks achieved the expected performance with the prepared electrodes and separators.

1 *Bipolar LTO/LFP electrode.*

2 *Ceramic separator directly coated on LFP cathode using water-based process.*

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