DEAR READER

Wind turbines have increased considerably in size and productivity over the past few years and focus is more than ever on reducing costs and improving efficiency.

FORCE Technology has been servicing the wind power industry since the very beginning and is a world leader in services related to the design, operation and maintenance of wind turbines.

Our services are within the areas of integrity management, experimental tests and simulations, non-destructive testing (NDT) as well as failure analysis, calculations, design verification and condition monitoring. All services are typically customised to solve a specific challenge.

Whichever situation you face, we shall do our utmost to service you thoroughly and in due time. Our highly skilled experts have been dedicated providers of services to the wind power industry for more than 75 years.

Please feel free to contact us if you have any questions or inquiries related to our services.

Enjoy your reading!

Olevid Andersen Clement
CEO
The WindSea concept is based on experience gained from the offshore industry. We wanted to increase predictability and ensure confidence and ease for our clients. This included optimisation concerning fabrication, access, installation, and maintenance.

Two concepts were developed
We designed two concepts, a jacket design and a floater design. The jacket was a simpler and less expensive design, while the floater was more comprehensive, producing more energy and further increasing stability.

Jacket design
The jacket design is suitable for 0-50 m water depths. It is module based with standardised units, which provides fast installation and flexibility regarding water depths and turbine size.

Benefits include:
- Reduced engineering and fabrication costs due to lower weight and a more efficient design
- Easy transport and installation with up to five jackets per barge:
  - Installation and piling in the same operation and the transition piece can be installed later
  - Installation in higher waves because of the reduced need for accuracy in landing

Floater design
The concept consists of a floating device, carrying three wind turbines. It is a semi-submersible vessel with three columns, each supporting one turbine. Two of the turbines face upwind, while the third faces downwind.

The vessel is moored to the sea bottom, connected to a turret at the vessels centre, thereby allowing the vessel to rotate. This allows the turbines to rotate according to the direction of the incoming wind. The rearmost turbine is higher in order to reduce the shadowing effect of the two turbines in the front.

The produced energy is proportional to the swept area of the turbine rotor, and increased blade length ensures high stability. The WindSea platform has a total output of around 10 MW per platform. A wind farm consisting of e.g. 30 platforms (90 turbines) will be capable of producing more than 1,200 GWh of energy a year, enough electricity for more than 60,000 households.

Main principles and benefits:
- Build complete platform at yard
- Tow with commissioned turbines
- Pre-installed anchor system
- Platform self-orient towards the wind
- Easy connection to mooring system
- Optimal power production
- Access for inspection and maintenance via boat or helicopter
- Major repair work at shore
- Modularised fabrication, allowing for repeatability and low cost

Testing & verification of concept
Using our expert knowledge within hydro- and aerodynamics, the concept was tested at FORCE Technology’s testing facilities in Lyngby, Denmark.

Wind tunnel tests
Wind tunnel tests were performed to document the efficiency and efficacy of the aft wind turbine. Furthermore, global loads and moments were measured and documented to evaluate mooring forces and turning moments.

Towing tank tests
The towing tank model tests investigated and documented the stability of the platform. The towing tank tests also tested the general functionality of the platform movements.

Development of a unique wind generation system
In order to perform the tests in the towing tank, we developed a unique wind generation system. The wind rack can accurately model the wind field including the wind profile in a sectional area of approximately 4x6 m. The system consists of a large high-pressure compressor and a rack of tubes fitted with high-speed nozzles. The rack efficiently transforms the towing tank into a very large wind tunnel.

For both the wind tunnel tests and towing tank tests, large efforts were put into constructing ultralight wind turbine wings to ensure the correct stabilisation contribution from the rotating wings. The wind turbine wings were made of a composite of glass fibre and foam to ensure the ultralow weight.
Due to the growing demand for green energy, the installed wind energy capacity is increasing each year. In crude figures, each MW installed capacity requires the use of 5 tons of composite material for the blades and therefore, today, about 200,000 tons of composite material is used annually to cover the demand. This figure is expected to increase every year towards 2020.

**ENVIRONMENTAL ASSESSMENT OF COMPOSITES**

Today, most of the composite materials used in wind turbines are disposed of by putting them on a landfill, without harvesting of environmental benefits. Considering the content of valuable raw materials in composites, there can be a significant potential in a sustainable exploitation of these resources.

**Beneficial end-of-life treatment for composites**

FORCE Technology works with all branches within the composite industry to find the best possible end-of-life treatment route for composite materials, both for production waste and for post-consumer waste.

We use information from producers to calculate both burdens and benefits associated with generic treatment routes like incineration, cement production, solvolysis, etc. The methods we use are internationally recognised, enabling us to provide companies with a balanced overview of their options.

**Broad competences ensure necessary documentation**

Companies may encounter hurdles in the process of implementing the best and most cost-effective solution for the environment. We provide the documentation requested by companies that are able to recycle composite waste. In those cases, our different departments co-operate to ensure that e.g. high-quality chemical analysis of materials and components is employed in your decision-making.

**TESTING OF FLOATING WIND TURBINES**

Recent years installations of wind turbines have been moving further and further offshore. The greater water depths call for new solutions like floating wind turbines. In order to fully take advantage of the enormous energy resources found offshore the best design must interact with the environment.

In our wind tunnels, we can measure the effect of each wind turbine and define shadow effects on the other turbines. We perform wind tunnel tests of floating wind turbine platforms with the purpose of acquiring data for mooring and stability analyses through determination of the global wind and current loads for the above as well as underwater parts of the structure, respectively. The tests can be performed with stationary or rotating blades.

The scale model is built in our in-house workshop. To ensure the correct stabilisation contribution from the rotating blades we typically construct ultralight wind turbine blades from a composite of fiberglass and foam.

The overall forces and moments on the platform are measured by means of a 6-component strain gauge balance. Three forces and three moments are measured simultaneously during each test run. The 6-component balance is fixed on a tilting mechanism enabling testing of the different inclinations of the platform. The exact draught and inclination angle are adjusted on the tilting mechanism.

The tests are carried out in one of our boundary layer wind tunnels, where a wind profile representing the ocean wind velocity and turbulence is established.
A new development & testing centre for the renewable industry

The brand new testing facility is located at a former shipyard near Odense, Denmark, with ideal infrastructure for shipping and handling of large structures.

Lowering the cost of energy along with increasing product quality, system durability and production efficiency are key issues for the wind industry. In close alliance with you, we ensure optimal solutions within developing and implementing advanced welding solutions, providing materials consultancy and testing solutions for your products and systems.

Competitive production using high-power laser technology

Lindoe Welding Technology (LWT) is a state-of-the-art laser facility for testing and developing new productions methods. The heart of LWT is two 16 kW disk-lasers, and when coupled in one fibre they can deliver up to 32 kW laser power on the work piece.

The high-power equipment together with the unique location at Lindoe Industrial Park makes it possible to introduce laser welding and laser hybrid welding for heavy section components.

We can help you test and implement high-power lasers within all aspects, e.g. process development, prototyping, small-scale production, implementation and training.

Can your system withstand the environment?

In the climatic test chamber, realistic atmospheric sea conditions can be simulated for large components, and even complete systems.

The climatic test chamber is equipped with three individual environmental systems:
- Temperature control
- Humidity control
- Saline spray.

The three environmental parameters can be individually or simultaneously controlled to realistically test harsh offshore conditions. In addition, accelerated tests can be conducted in combined parameter cycles.

At Lindoe Component & Structure Testing it is also possible to test a variety of land-based equipment, e.g. onshore wind turbines, transport systems, warning systems, and lightning systems. In addition, split-systems like heating/cooling systems consisting of an indoor and an outdoor module are tested and verified for both corrosion resistance as well as performance.

Testing, evaluating and optimising your equipment properly before installation will confirm lifetime performance of your product.

Mechanical testing for innovation & validating robustness

Mechanical testing of subcomponents is widely used to determine whether these comply with standards or other requirements. The mechanical test bench is ideally suited to test not only large subcomponents but also complete full-scale systems.

The test bench has a large strong floor and an L-shaped strong wall along two sides. Full-scale testing setups utilising servohydraulic actuators can apply three-dimensional loadings to simulate relevant environmental effects, e.g. wind and waves.

Static ultimate load tests or dynamic fatigue tests can be tailored to the specific loading patterns or patterns present in operation. Efficient standard tests and customised loading and data acquisition are available to support all programmes.

The ability to test full-scale systems will give you the documentation for the durability of the structure based on real-world effects.

Be one or two steps ahead of your competitors

Let us assist you with preparing a suitable development and test programme for your product and be sure that your product will succeed once it is installed on- or offshore.

Lindoe Welding Technology
- Up to 32 kW laser power
- 2 flexible robot installations
- Wide variety of handling equipment
- High-power welding and surface modification.

Climate chamber
- Test chamber: 8 x 8 x 14 m
- Temperature range from -35 °C to +60 °C
- Humidity control from 10 %RH to 100 %RH
- Saline spray from various directions (e.g. from wind direction).

Mechanical test bench
- Floor sized at 9 x 20 m
- Reaction walls, 4 m in height
- Applied loads up to mega Newton
- Various accelerated test patterns possible.
It is crucial for your market position to deliver fully functional and high quality blades fast and continuously. Therefore, blades testing requires being processed efficient, fast and without any disruption. We recognise that. Our team has both long experience since the beginning of the wind turbine industries establishment in the early seventies and total dedication to contribute to your production efficiency.

BLAEST, formally known as Blade Test Centre A/S, is a privately held company, which implies for you that we are independent and will always prioritise our customers’ affairs. Our shareholders are FORCE Technology, DTU and DNV•GL. Our test centre offers testing of blades up to 80+ meter lengths. We aim at meeting the needs for testing even larger blades, when required by the market. Transport to the test site is carried out according to client agreements. If you prefer so, we may also test on-site.

Your demand for discretion and confidentiality is our duty. We execute tests for a wide range of OEM producers on a global scale.

Static test
Static tests are carried out as a multipoint load application in vertical direction or in other angles as the customer may require. BLAEST uses a mechanical load system, which introduces loads in multiple points simultaneously. The load introduction system works with very small deviations between target load and actual load and can complete a static test within few minutes. Data are recorded with a sample rate up to 250 Hz.

Flap-wise fatigue test
Fatigue load blade tests are performed to determine inherent fatigue properties of a blade, predicting the long-term structural performance during the designed blade lifespan. The reported data enables certifying bodies to compare measured data to the calculated data of the design criteria. Thus full-scale blade fatigue tests are often an essential part of the approval process.

Fatigue tests may be performed in different ways. Edgewise fatigue load testing is normally performed in horizontal orientation and excitations are forced by rotating eccentric masses. For larger blades, BLAEST developed an electrically driven exciter with a pushrod connection to the blade.

Modal analysis
Modal analysis is the process of determining the modal parameters, which are then sufficient for formulating a mathematical dynamic model. Modal analysis can be accomplished through experimental techniques. It is the most common method for characterisation of the dynamic properties of a mechanical system. The free dynamic response of the wind turbine blade may be reduced to a discrete set of modes. The modal parameters are:
- The modal frequency
- The modal damping
- The mode shape.

BLAEST ensures responsibility and continuity from start to end in the blade testing procedures. We know this is essential for taking your high demand for quality in blade production to the next level. The blade design verification is crucial to your production and flexible testing project set-up guarantees to match exactly your needs for blade testing, which results in keeping your production efficient.
MECHANICAL TESTING

The four Scandinavian locally based testing laboratories within the FORCET Technology Corporation present a unique range of test facilities for fast, precise and cost-effective solutions. Apart from providing conventional test methods such as tensile, impact or bend testing, the laboratories offer advanced test methods in the field of mechanical testing. Steels – rolled, forged or cast items – may be delivered with materials certificates as documentation for chemical composition and mechanical properties. When verification is needed or certificates are lost, testing in accredited laboratories is vital in order to accept items such as wind turbine components.

Fracture mechanic testing
By using the possibilities in fracture mechanic testing, brittle fracture, crack growth or material defects are analysed and most likely avoided. Huge structures require comprehensive knowledge by engineers, designers or developers no matter the nature of the structure:
- Offshore platform
- Wind farm
- Foundation onshore or offshore.

The most up-to-date software to analyse fracture mechanic test results is at your disposal in the mechanical laboratory. Typical fracture mechanic testing methods are:
- CTOD testing (crack-tip opening displacement)
- Fracture toughness testing to determine KIC or J-integral
- Crack growth rate.

Besides receiving your test result, our design and stress analysis experts are at your service to guide you or calculate consequences based on the test results.

Fatigue testing
Understanding materials is essential, as designs are getting more and more advanced. You may wish to have that knowledge to pursue the most cost-efficient design phase, during operation or in worst case after failure. Our well-equipped test machines operate with high as well as low frequencies and provide you with fatigue curves within a few days.

The fatigue testing may be performed through:
- Fatigue testing with a specific load for a specific number of cycles
- Determination of S/N-curves
- Determination of Vöhler-curves
- Determination by staircase method.

Damage & failure investigations
In order to clarify the cause of damage to or failure in components, the following investigations often call for verification of the actual properties of the failing component in order to verify compliance with specifications and material documentations. Samples are cut from the failing component and sent for tensile testing or - in case of insufficient sample size - alternative hardness testing in order to verify the strength of the material. Ductility may be verified through tensile or bending testing. The toughness property is determined by impact testing or for special applications by crack tip opening displacement testing (CTOD). These test methods may reveal insufficient material toughness as the cause for a potential brittle fracture. Specific zones such as weld zones, heat affected zones or hardened surface layers may be the origin of failures, and hardness tests may be used to map the properties of such zones.

With the advantage of our internal workshop for CNC-machining of test specimens, delivery time is reduced and adjusted to your requirements.

During the investigations you will always benefit from working close together with our in-house design experts.
Whether the wind turbine is planned positioned inshore, at-shore or offshore, the structural design must be based on environmental conditions, expected design life and inspection frequency. An essential part of the design premises is generally determined by the installation phase, why we ensure a strong focus on this during the concept development.

For inshore installations, road access to the wind farm may easily pose a challenge, while at-shore fields often experience challenges with access to infrastructure as well as geotechnical properties of the site. For offshore fields, the installation is generally carried out by boats and crane. During this phase, acceptable weather conditions easily becomes a bottleneck, independent of whether the structural design is fixed or floating.

Modifications of wind turbine structures are often related to repair and corrosion protection. The latter is achieved by use of anodes, where experience and knowhow from offshore structures is used in order to achieve an optimum solution.

Designing large structures with global design in combination with local design and analyses is everyday business for us. This includes non-linear analyses to document the sustainability of the structure with regards to accidents or extreme conditions. CFD analyses are used to simulate flow of either seawater or air, and thereby calculating the forces affecting the structure.

Our test facilities include test chambers for xenon, UV, salt spray and humidity testing, the latter with options for the programmed addition of corrosive gases.

We have many years of experience in performing the tests and interpretation of the test results. With our material experts and analysis facilities, we are able to conduct evaluation of test results and relate observations from the tests to practical use.

Accelerated tests makes it possible in a short time to detect weaknesses and defects in materials, surfaces or surface treatments and thereby avoid large costs for replacement or maintenance.

We perform tests according to recognised ISO, EN, ASTM and Norsok standards. Besides standardised testing, we also offer special testing customised and adjusted to the actual task.

Paint & polymeric materials

Plastic, paint, varnish, rubber and other materials are affected by sunlight, temperature, humidity and other environmental conditions. This can result in change in colour, radiance, formation of blisters, delamination or change in mechanical properties.

We can test the durability or resistance against degradation or change with xenon and UV exposure, optionally combined with exposure to water or moisture. Xenon and/or UV test may also be combined with salt spray test, which might be relevant for paint, adhesives or sealers used for corrosion protection on metallic materials.

Metals

Accelerated corrosion testing with exposure to salt spray or humidity enables us to test the protective effect and durability of surface treatments on steel, aluminium or zinc surfaces. Exposure in humidity chamber may also include the addition of sulphur dioxide, which increases the corrosivity of the test considerably.

Besides the relatively short duration needed to document the durability of the protection, the accelerated tests can also detect improper or insufficient surface treatment. If relevant, the tests may include freeze-thaw cycles.
Since the first jack-up vessel sailed offshore loaded with wind turbines, FORCE Technology has been an essential partner in the development process of such ships. Over the last couple of years, we have been involved in analysis and testing of several designs of large installation vessels in our towing tank and wind tunnels.

**Early design stage**

In the early design stage, we can perform seakeeping and dynamic positioning (DP) calculations to determine the motion characteristics and to evaluate the operational window with respect to the jack-up procedure.

**Detailed design stage**

As the design develops, we can provide our clients with a comprehensive test package including towing tank tests (resistance & propulsion, seakeeping, manoeuvring, thruster interaction and DP tests) and wind tunnel tests (wind & current loads and wind climate for helicopter landing operations).

The main objectives of the wind tunnel tests are to determine the wind and current loads on the vessels for different elevations of the jack-up legs and jacking above the water surface. The drag of the large jack-up legs extending down to 45 metres below the vessel is often the governing factor with respect to the station-keeping abilities of the vessel. Therefore, it is important to accurately predict the drag of the legs for both wind and current.

An extrapolation of the measured model scale drag of the jack-up legs to full scale is needed for both wind and current loads. To accomplish this, a section model of the jack-up legs is tested in FORCE Technology’s high-speed wind tunnel at a wind speed equivalent to full-scale Reynolds number.

The data obtained from the tank and wind tunnel tests are used to update the evaluation of the operational envelope of the entire procedure from port to installation site.

**VESELS FOR INSTALLATION OF OFFSHORE WIND TURBINES**

One of the biggest challenges in the construction of offshore wind farms is the installation process where the wind turbines have to be installed on the seabed. In order to do so, one needs a purpose-built vessel with jack-up capability and heavy duty cranes to enable the installation of the wind turbines.

Ice accretion on turbine blades will reduce the turbine’s efficiency and may cause undesirable aerodynamic vibrations or even instability. Ice accretion on instruments and measuring equipment may lead to erroneous readings or even permanent failure. We address these issues by testing aerofoils, wing sections, wind turbine components and measuring equipment in a velocity range up to 30 m/s in critical climatic conditions, i.e., conditions that may lead to ice accretion.

**Climatic wind tunnel**

The climatic wind tunnel has a test section of 2x2 m², and its cooling unit is capable of controlling and maintaining a long-term average temperature down to -8°C, depending on the wind speed. A rotatable spray bar system is located in the settling chamber after the wind tunnel’s honeycomb and allows the simulation of in-cloud icing conditions.

**Experimental work**

Extensive research work has been done in the climatic wind tunnel in joint research projects between the Technical University of Denmark (DTU) and FORCE Technology. More recently, the research on airfoils in the climatic wind tunnel including the in-cloud icing system and experimental work with airfoils has been conducted. This work includes static tests conducted with airfoil section models - both in dry and iced states. The iced state is investigated simulating several in-cloud icing conditions, e.g., generating mixed rime and glaze ice accretions.

### TEST OF ICE ACCRETION ON WIND TURBINE BLADES

For wind turbines and measuring equipment placed in areas with frequent or occasional sub-zero temperatures, the risk of ice accretion must be considered. These issues may be addressed in FORCE Technology’s in-house facility, the closed circuit climatic wind tunnel.

Contact: wind@forcetechnology.com

An installation vessel ready to be tested in our wind tunnel.
SITING OF WIND TURBINE FARMS IN COMPLEX TERRAIN

For wind turbine farms in hilly or mountainous terrain, it is necessary to consider the wind conditions across the specific site in order to ensure an efficient location of the wind turbines.

Wind tunnel simulations
In the wide boundary-layer wind tunnel, FORCE Technology is able to test large-scale terrain models with a detailed representation of the site and its surroundings. Our tests provide the developers with an accurate description of the wind conditions for possible locations of the wind turbines.

In addition, the tests may provide the wind conditions for planned positions of anemometers at or near the site and compare these with existing meteorological stations in the site’s vicinity.

Based on digital maps of the site, the terrain surface is described using 3D CAD-software for our automatic milling machine. This permits a fast and precise production of the model in 1:1000 or 1:2000 since the terrain model investigations are normally conducted for areas covering several square kilometres.

This approach to evaluate the wind conditions at wind turbine sites is accurate and also cost- and time-effective.

NON-DESTRUCTIVE TESTING (NDT) SERVICES

‘Securing your structures’, is the essence of our non-destructive testing (NDT) services. For several decades, we have provided a wide range of NDT services, striving to be your experienced, reliable and trustworthy partner.

FORCE Technology employs more than 150 NDT inspectors and NDT specialists; all certified according to ISO 9712 and ready to provide quality services at any given time of the day 24-7, 365. For your convenience you can order your NDT service online.

Our local offices are ready to help, should you come across testing and examination requirements such as EN 1090, EN 13480, EN 13445, EN 12952 and EN 13941.

Services within the wind turbine industry are e.g. examination of blades and components with digital radiography or our in-house developed automated ultrasonic systems (P-scan and T-scan), or ensuring deliveries by client/third party supervision.

The most common testing methods are:
- Radiography
- Ultrasound
- Magnetic particle
- Liquid penetrant
- Remote controlled visual testing
- Phased array ultrasound
- Eddy current.

We perform FUWI (fixed ultrasonic weld inspection) on wind turbine towers and foundations with 100% documentation of all tests.

In need of testing or inspection on industrial facilities, tanks, containers, pipelines, cranes and moving equipment, we are experienced in helping you comply with your specifications.

We fulfil requirements from the Danish Maritime Authority as well as requirements from classification companies such as DNV•GL and Lloyds to perform inspection on ships and other marine installations. This includes all offshore installations and wind turbines.

If you are undertaking steel construction work outside Denmark, our qualified inspectors can carry out contractor inspection on your constructions. We offer single visits to your supplier as well as ongoing on-site inspection during the entire building process. This provides you with the comfort that your project is delivered in accordance with your specifications.

As documentation of our testing and inspection work, an electronic report is issued and made available to you through our online NDT reporting service.
PHASED ARRAY ULTRASONIC TESTING

Phased array ultrasonic testing (PAUT) is a method that has become entrenched in NDT during the past decade and has numerous applications in production and in-service testing of wind turbines. The benefit is a fast overview and documentation of the examination data, and higher probability of detection than manual ultrasonic testing (UT).

With an automated phased array system, the ultrasonic and position data are recorded and processed, and the signals from flaws will be correctly positioned in a projected or a 3D view.

PAUT is an ultrasonic test method based on the phased array technique. Phased array probes contain a number of separate elements that can be pulsed separately.

By combining the transmission of the different elements, the phased array method makes it possible to electronically control and sweep the beam angle, focus and position. Consequently, a large volume can be examined with a rather small footprint, which simplifies the examination and makes it possible to inspect objects that are more complex with limited surface access.

Replacing a manual ultrasonic examination of welds with phased array line scan will result in a considerably shorter examination time.

An example of PAUT applied on a complex item with limited surface access is the test of fatigue cracks initiated from the bolt holes in aluminum inserts on blades. This might cause damage of the blades or even complete failures and has been a problem in certain types of wind turbines.

In general, PAUT allows for many new applications within the field of ultrasonic testing. 3D automated phased array solutions make it possible to inspect complex objects, and perform accurate sizing and positioning of flaws. The 3D processing considers the complex geometry and calculates how the sound reflects inside the object. The result is a precise 3D map of the object that shows the ultrasonic indications of flaws and corrosion.

THIRD PARTY INSPECTION SERVICES

It is crucial that your wind turbine is manufactured according to the current standards and in accordance with your requirements. Quality assurance minimises unpleasant surprises in your production.

Quality assurance reduces costly repair

Quality assurance is about delivering the correct product in the expected condition and at the agreed time, place and price.

You avoid costly repair by safeguarding against variations and unnecessary changes in design and repair during production, which delays and increases the cost of production.

By having a third party inspector present, the quality of the products is monitored and errors are noticed and corrected in due time during production.

Technical expertise from start to end

We offer technical expertise from start to end during production of welded steel structures and the following paintwork. The inspection programmes are prepared in concert with you and in accordance with your wishes.

We audit suppliers before and maybe parallel to the course of production. This includes evaluation and revision of the supplier’s production facilities as well as examination of procedures and specifications for production and production control. We also perform random NDT verification of steel and surface treatment.

We participate in meetings with your suppliers worldwide, where we offer current assistance in connection with treatment of possible deviations, if any, and corrective actions.

Many years’ experience with third party inspection

We have contributed with third party inspections within manufacturing of foundations, towers, platforms and general surface treatment and corrosion protection in the largest offshore projects around the world.

As the owner’s consultant and representative on the production site we ensure:

• Product quality
• Detection of deviation from your specifications
• Precise and timely reporting.
We have developed several scanner systems for automated ultrasonic inspection of blades, in production and on-site. Our scanner systems differ in size and method; some are forklift-mounted, others are manual and some run on tracks.

For you to choose the perfect scanner you have to take different factors such as, the size of the element requiring inspection, your production capacity and requirements for examination speed into account.

Blade testing in production

Our range of scanner systems for automated ultrasonic inspection of blades in the production features three forklift-mounted scanners and one go-cart looking scanner.

Mobile blade scanner
The mobile blade scanner system, AMS-60, is capable of scanning vertically oriented blades. It indicates fiber misalignments and UD fiber waviness (wrinkles) in spar caps and girders, along with laminate integrity, delaminations and voids. The AMS-60 requires one operator and completes an entire blade inspection in 2-6 hours.

Mobile blade array scanner
The mobile blade array scanner, AMS-71, is the fastest system for a complete automated ultrasonic inspection of vertically oriented rotor blades. A full inspection on a 70-80 meter long rotor blade is done in less than one hour, both sides covered. The AMS-71 monitors and sizes intra-laminar and bonding defects as well as UD fiber waviness.

Mobile blade track scanner
The mobile blade track scanner, AMS-69, scans the blade along a track in 4-5 meter segments. The track ensures stability and accurate positioning throughout the inspection. The AMS-69 gives you an accurate surface scan of blade spars and indications of reinforcement areas.

Crawling mobile scanner
Our crawling mobile scanner, AMS-46, is a go-cart looking scanner for automated ultrasonic inspection of horizontally positioned rotor blades. The AMS-46 provides an indication of delamination and dry areas in girder composites as well as reinforcement waviness, with wrinkles and undulations in load bearing parts. A full blade scanning takes up to 6 hours.

Blade testing on-site

The requirements to scanners for on-site blade testing differ from scanners for production control. Our manually operated scanners are small in size and weight, which makes them easy to set up for inspection. The automated scanners are attached to the blade with e.g. suction pads, thus the equipment is heavier and takes a little longer to set up.

Manual line scanner
The manual line scanner, MWS-6, is a manually operated scanner, mainly used for semi-automated inspection of composite materials. The scanner is an ideal portable solution for random on-site spot checks on erected blades.

The MWS-6 is an ideal supplement to a full size scan, as you can pinpoint new areas of concern in advance or go into depth with those already known.

Automated track scanner
The automated track scanner, AMS-64, is made for automated ultrasonic inspection of selected areas on vertically and horizontally oriented rotor blades. Its primary use is for on-site inspection; however, it is also useable for spotwise inspections during production or in laboratories. The scanner indicates delaminations, adhesive defects and dry areas.

Customised solutions
The mentioned scanners are just some of our solutions. We have also created a broad range of customised production and on-site inspection solutions. If you did not find a solution matching your needs, please do not hesitate to contact us.
TOWER TESTING SOLUTIONS – IN PRODUCTION & ON-SITE

We have developed automated ultrasonic inspection systems for tower testing in production and on-site. One of the systems is even applicable in both situations. Choosing the perfect scanner for your job depends on different factors such as the size of the element requiring inspection, your production capacity and requirements for examination speed.

Weld inspection in production
The wind turbine tower scanner, AMS-41, is the perfect choice if you require a fast and reliable automated ultrasonic inspection of welds on wind turbine towers. The scanner is used in the production for inspection of circumferential butt welds and flange welds.

One person easily operates the scanner and it only takes 10-15 minutes to do a complete inspection of a circumferential weld. Thus, the AMS-41 reduces the inspection time from hours to minutes regardless of the number of flaw indications, the number of man-hours needed, and the overall production time.

Weld inspection on-site
Our automated general purpose scanner, AGS-2, is a scanner for automated ultrasonic inspection of all types of welds. It is very popular in the wind energy industry and the continuous development ensures a highly reliable scanner. The AGS-2 can be used for inspection in the production as well as on-site.

The scanner is particularly well suited for on-site inspection of circumferential welds and longitudinal welds in wind turbine towers. It is remote controlled and requires a minimum of manpower, as most tests only require one operator.

Another scanner, which is well suited for on-site weld inspection is the automated universal scanner, AUS-5. It is a small, rugged scanner with magnetic wheels. The AUS-5 is designed with special attention to small size and lightweight for easy transportation and set-up.

The small size and lightweight makes it a good alternative for on-site weld inspection. The scanner is easily operated from e.g. a platform or working basket.
MATERIAL SELECTION

If you select the correct materials for your product already in the design phase and give it the optimal corrosion protection by coating or by cathodic protection, you and your customers get the best conditions for keeping the functionality and appearance of the product in its product life. By drawing on our unique combination of wide theoretical knowledge and practical experience of many years in the fields of metallurgy, corrosion and coating, you are certain of good results from the beginning.

Achieve a long product life with the correct choice of material

When you design your product, you put a lot of money, energy and consideration in achieving the best possible function, good appearance and high reliability. Corrosion, wear and fatigue resistance may not be the first factors you consider. However, material selection is crucial to obtain a long product life and to avoid failure during operation – for instance due to inadequate mechanical strength – or unacceptable appearance due to corrosion products.

If you choose the correct materials for your product from the beginning, you can prevent damage deriving from corrosion, wear and mechanical impact. In many cases, you may completely avoid corrosion by choosing a resistant material for its actual environment of use. Alternatively, you can prevent corrosion by the use of coating (paint, metallic coating), by cathodic protection or by controlling the aggressive environment (water treatment, dehumidification).

An aggressive environment increases the material requirements

All metals may corrode if the environment is sufficiently aggressive, and mechanical impact will often increase the risk of corrosion failure. The price of the material often determines the price of a product, and therefore products are constantly optimised to save weight, materials and costs of processing. This means that the tolerance for corrosion, wear and mechanical impact is constantly reduced which is why all these factors should be considered in the design phase.

Choice of material is a multidisciplinary field, and our specialists possess the state-of-the-art knowledge of metallurgy, mechanical properties, corrosion, coating, wear etc. – depending on the actual product. If you consider replacing metallic components with parts made of plastic (polymers) or glass fibers (composites) to save weight or to obtain a lower price, we can be of assistance with information about requirements for the material so that the replacement becomes a success.

Wrong choice of material influences product life

The incorrect choice of material may cause product failure and production shutdown within only months, even though the estimated service life was many years. If you choose the wrong stainless steel for a product, or the steel is treated improperly during welding or processing, it may corrode quickly. Thus, a product with an estimated service life of 20 years may last a few months only. When you assess how new and advanced materials or innovative surface modifications will be able to improve your product, we can help you find the optimal solution through a combination of knowledge, analysis techniques and tests.

By including FORCE Technology in your material selection, design review and consultancy on operations early in the planning phase, you can avoid or minimise corrosion to an acceptable level. Our specialists have deep knowledge and many years’ experience from many industries all over the world, and we can help you avoid unnecessary damages.

It is often in the interface between different fields that standard solutions don’t work. We can draw on specialists within metallurgy, corrosion, concrete, plastics, chemical analysis, strength calculations and many more. We give lectures at conferences and in professional networks, both nationally and internationally, and we constantly broaden our knowledge and network. If the damage has already occurred, we can perform inspections and status assessments of the equipment and advise on improvement of the construction, corrosion protection and operation so that future damage resulting from corrosion is minimised.
COATINGS FOR CORROSION & WEAR PROTECTION

Corrosion is inevitable… but you may delay attacks and breakdowns with the right coating.

Protection with coatings never ends
We offer professional consultancy and services regarding surface treatment of wind farm structures; both on- and offshore are among our specialties. Our certified inspectors and material specialists have extensive experience in preparing specifications for material selection and surface treatment as well as on-site inspection including failure analysis and troubleshooting.

Protection of material
In the initial phase, we can assist owners and contractors in evaluation of the protection against wear and corrosion. We select the optimum coating types and systems for the individual parts of the wind farm, and tailor-make control procedures before, during and after the protective coating application.

Selecting materials
As a supplement to corrosion and wear protection by coatings, FORCE Technology also offers consultancy services on the choice of the optimum resistant materials. It may be advantageous to have special parts galvanised or thermally sprayed instead of being painted, or introduce ceramics, particular alloys or composites. The cost benefits by introducing these materials and means of protection can be verified.

Thermal spraying
Corrosion protection using thermal spraying can significantly reduce the cost of replacement and/or redesign of critical components as the process permits local improvements to the surface. The spraying process will not induce material changes in the base material, and the surface properties can be tailored to the specific needs for any given application, e.g.:
- Repair and refurbishing of damaged surfaces on costly parts, e.g. shafts, bearing houses, etc.
- Protection against wear of critical areas by application of hard and wear-resistant layers
- Corrosion-resistant surface coatings.

We perform repair and optimisation of single components as well as high-volume production in our state-of-the-art thermal spraying facility.

On-site maintenance services
FORCE Technology provides on-site consultancy on maintenance. A typical survey carried out by our certified inspectors and material specialists will give our customer a report including recommendations on repair, coating systems and inspection levels during repair. While the wind farm is in operation, we offer coating condition surveys with the aim of designing the best and most economical way of protecting your assets during its upcoming maintenance period. During the overhaul, our certified inspectors (FROSIO NS 476) monitor all coating operations to certify that all planned repairs are performed according to specifications and mutual agreements. An independent survey or inspection report from us always includes proposals aimed at future protection.

Failure analysis
In the event of claims, our impartial surveys will provide the owner with solid technical information for the contract negotiations and court litigation. Our forensic services comprise (but are not restricted to) an investigation of root causes of coating failures and corrosion damages. These services include professionally executed microscopic and chemical analysis of coatings, material quality, chemical composition of corrosion products etc. to support the investigations.

Your benefits:
- Verification by a certified and professional partner that your product meets all requirements of contractual specifications and relevant product standards
- Competent supervision during all phases of a project
- Supervision by certified inspectors (FROSIO NS 476) of coating application on new constructions and during maintenance
- Competent consultants supporting or replacing in-house staff
- Professional consulting and training.
With our extensive knowledge of welding technology, we can help you assure a good welding quality in your production. We can assist you before, during and after your welding work. FORCE Technology provides professional consultancy from the first idea to the final delivery and documentation.

WELDING CONSULTANCY & INSPECTION SERVICES

Below, we have listed a variety of our services within welding technology to give you an idea about how we can assist you.

Welding consultancy
Our staff of welding engineers, welding technicians and specialists with many years of experience offers both practical and theoretical consultancy on welding related issues. We are fully familiar with relevant welding standards and legislations. We advise on interpretation of codes, rules, standards and tenders in relation to your project. Furthermore, we advise on optimisation of welding processes and selection of equipment. We troubleshoot welding problems, whether related to the welding process or the resulting material properties.

Welding supervision/inspection
In order to avoid the risk of quality issues it is important to perform inspection both prior to, during and after welding. This is crucial whether you are the contractor, the wind farm owner or a supplier. Review of the complete documentation package related to the project is also one of our specialties.

Qualification of welding procedures
We supervise and can verify procedure qualification tests according to EN ISO 15614, ASME and other relevant standards.

Certification of welders
Certifying welders and welding operators according to EN ISO 9606 / EN ISO 14732, ASME IX and other relevant standards as well as approval according to the PED directive is also something we can assist you with.

Specialists
Our supply surveyors, auditors, material specialists, structural engineers, welding specialists and NDT specialists will be happy to assist you in meeting the technical rules, standards and other specific requirements, e.g. from the classification societies.
Monitor investment & avoid expensive repair
Preventive or planned maintenance is an often used maintenance strategy within the offshore industry. However, when using this strategy, one can expect that the wind turbines maintain their functionality throughout their design life, which from experience within the turbine industry, is not always the case. While other parts of the wind turbine often reveal flaws through operation, this is not the case with the foundation.

In order to ensure that offshore wind turbines maintain their functionality, and avoid large costs in connection with repair and retrofit, we recommend implementing accurate monitoring of loads, fatigue, stress and corrosion.

Advantages of monitoring systems:
- Early warning of structural changes that suggests reduced service life
- It allows you to tune the operation to avoid ultimate loads and fatigue damage
- Use of data for corrective actions and for optimisation of sub-components and design
- Failure-cause identification in order to prevent recurrence
- Online measurements of functionality of the cathodic protection (CP)

Monitoring contributes to design optimisation
A damage in the foundation is often caused by unforeseen loads on the structure or external factors, which unfortunately have proved to entail large and costly repairs. A monitoring and warning system in the foundation may give notice of several conditions that may lead to a shortened service life.

Monitoring systems can, among others, measure the following:
- Dynamic response
- Mechanical displacement and component stresses
- Corrosion
- Functionality of the cathodic protection (CP)
- Erosion of the sea floor (Scour).

Another feature of the monitoring system is the possibility to systematically evaluate and assess data in order to determine the condition of the particular structure monitored, and to extrapolate the result onto other structures in the vicinity. Data is collected, either manually or by online monitoring, and may be automatically processed to give real time decision support and long term trending.

This data can be used to optimise the operation with regards to structural integrity, or if needed, act more drastically to avoid further damage in the turbine structure. Gathering operational data for this somewhat inaccessible part of the turbine is invaluable for design optimisation, but also for the learning process for future developments.

Tailored solutions & expert consultancy
Our monitoring systems are customer-specific, and we design and optimise a monitoring solution that is adjusted according to your need for information, within your budget.

Further to the fact that FORCE Technology can design, supply and install unique monitoring systems, we can also be of assistance with the subsequent data processing, evaluation, assessment and consultancy.

With our unique monitoring systems and our comprehensive know-how of material types, corrosion, structural integrity, fatigue, stress and expected life calculations, we are able to give you the best possible advice.

Dynamic behaviour
We provide continuous monitoring installed in the tower and foundation or at identified hotspots for fatigue stress or measured and extrapolated stress level, showing vibration information like Eigen frequencies and dampening of the structure, and the stress cycle widths.

Sensors
- Strain gauges
- Subsea strain sensors
- Inclinometer
- Accelerometer
- Scour measurement

Corrosion
We offer measurement of corrosion rate, potential for further corrosion, functionality of the cathodic protection, and evaluation of oxygen concentration inside the foundation.

Sensors
- H2 sensor
- H2S sensor
- Temperature sensors
- Reference electrodes
- pH meter
- Water level sensor
- O2 concentration sensor

Scour
We provide scour placing on the foundation and measuring of the dynamic changes of the sea floor over time.

Sensor
- Acoustic echo sender/receiver

Contact: wind@forcetechnology.com
Benefits of CM systems

A complete condition monitoring system consist of data from structural monitoring sensors, environmental data such as wind, wave height and currents, SCADA data from the operation and inspection findings, in combination with a true structural model. Combining data and calibrating the structural model based on the actual loads and structural responses, provides the operator with a digital twin.

The digital twin is the means to run simulations and “what-if” scenarios, design verification and the extreme load case assessments. It also allows for comparison and trending between expected and measured responses. Furthermore, it makes it possible to enhance the integrity management of the unit, by extrapolating loads from a discrete number of sensors to identified hotspots in the complete unit.

From an asset point of view, extrapolation of results to identical units in the wind farm that is not as elaborately monitored, is a feature that provides added value. This may reduce the cost of the inspection program, where inspection is focused on the hotspots that have been exposed to damage from the operation, and on the units in the asset that are at most risk from an environmental data point of view.

Information generation

Based on identifying changes in the Eigen frequencies and damping from the frequency domain, and calculating the extrapolated loads in the time domain, we can assess fatigue damage, scour status, changes in the pile-soil interaction, floater mooring system or the general condition of the unit.

Through active use of the digital twin together with the actual measured responses and running online automatic processing, we obtain a visualised representation of the actual condition of the unit in a graphical user interface (GUI).

Alarms and warnings are based on raw data and processed data as in the form of thresholds, extreme events and deviations in trends and projections. By early identification of potential damaging conditions, appropriate actions may be taken to mitigate or reduce further damage, through inspection programs, modifications to structure or soil, or by operating procedures for load cases resulting in damage.
The wind energy industry has adapted their requirements for quality, health, safety and environmental (QHSE) management systems to those of the offshore industry, forcing the players in the wind energy industry to demonstrate effective QHSE management. Furthermore, quality requirements from the automotive industry are increasingly adopted by the wind energy industry, together with the zero defects philosophy.

**QHSE - MANAGEMENT SYSTEMS**

The wind energy industry has adapted their requirements for quality, health, safety and environmental (QHSE) management systems to those of the offshore industry, forcing the players in the wind energy industry to demonstrate effective QHSE management. Furthermore, quality requirements from the automotive industry are increasingly adopted by the wind energy industry, together with the zero defects philosophy.

**Improving performance**

FORCE Technology offers consultancy services to improve the efficiency of QHSE management and the customer satisfaction. Our consultants have great experience with QHSE management systems from the offshore and wind energy industry.

With our consultancy services, we focus to improve the following:

- On-time delivery (OTD)
- Supplied delivery quality (SDQ)
- Lost time injury frequency rate (LTIFR).

Our aim is to ensure our customers an internationally recognised competence level in their management system as well as continuously improve their process efficiency through competency development of their employees.

As one of the largest providers of courses in Denmark within this area, we offer a large number of QHSE related courses as well as customised courses. Visit our website for more information and course registration.

A co-operation with FORCE Technology on improvement of your QHSE management can ensure effective compliance with the following:

- Company policy
- Legal requirements
- ISO 9001 quality management systems
- ISO 14001 environmental management systems
- OHSAS 18001 occupational health and safety management
- PPAP production part approval process
- FMEA failure mode and effects analysis.

**Inspection as a supplement to management audit**

We offer to evaluate and document the fulfilments of specified requirements related to product, process, person or management systems. Technical performance of your business is ensured by inspecting and assuring that the management system will continually deliver the specified technical performance.

Our inspectors are highly qualified technical experts, and our inspection services focus on production or service-related specifications.

In order to secure cost-effective integrity management of wind farms, inspection and maintenance planning should be handled as a dynamic process, with continuous updates based on gathered condition data during operation. Our core inspection management process for maintaining the wind farm integrity is shown in the figure above.

Confidence through science & experience combined

With experts from various disciplines, we provide accurate identification of degradation mechanisms and integrity threats during the design and operational phase of the project. We apply risk-based approaches, such as risk-based inspection (RBI) and reliability-centred maintenance (RCM), in order to ensure a proper identification of vital components and optimise the inspection and maintenance strategy.

Risk-based models reduce inspection and maintenance costs as well as asset downtime by preventing costly failures from happening, while simultaneously reducing unnecessary interventions, such as annual inspections on low failure risk components. This allows you to focus your resources more strategically, while maintaining operational safety and stability of the wind farm.

We strongly believe that an approach that integrates our knowledge on integrity management with our expertise within other complementary key areas such as NDT, corrosion management and structural integrity, will ensure an effective management of inspection and maintenance operations, hence maximising the return on renewable energy investments.
Principles of passive thermography inspection.

Condition inspection of installed blades
Heavy wind and environmental conditions have a great impact on blade surfaces and laminated rotor blade structure. Due to different load and stress situations, damages like erosion, delaminations and cracks can appear. To prevent critical damages or even complete failure, the condition of the blades should be inspected regularly, utilizing different non-destructive inspection methods, e.g., visual and thermal infrared inspection techniques.

Periodic examination of the FRP rotor blades, with a visual and infrared imaging system, can detect operational problems before they become serious and allow for effective response planning. In this mode of operation, those inspection techniques are valuable predictive maintenance tools.

Thermal infrared condition inspection
Infrared thermographic inspection technique (IRT) is a non-contact and non-destructive inspection method which provides visualization of thermal patterns in various systems, such as the wind turbine rotor blades.

In passive thermography, the features of interest are naturally at a higher or lower temperature than the surroundings. The passive application is based on the advantages of climatic changes or heat differences of the sun illumination. In Northern locations, the changes in temperature from night to day can reach more than 20 °C within few hours.

The temperature of the rotor blade surface, which is directly illuminated by the sun, is in the wintertime 15 °C - 20 °C warmer than the reverse side. These huge temperature differences can be used to detect not only surface defects but also structural defects in the blade.

Detectable manufacturing uncertainties:
- Delaminations
- Foreign bodies
- Missing adhesive and adhesion
- Thickness variations.

In-service defects:
- Erosion
- Impact damages
- Delaminations
- Bondline failures.

Integrated drone system for visual & thermal inspections
FORCE Technology’s integrated drone system provides data capture for on-site analysis and evaluation of the condition of the blades and structure of each wind turbine asset. The system is easily deployed and mobilised to multiple locations in a wind farm with minimal time delay. This allows more efficient survey and analysis imagery than traditional telephotography or manual inspection methods.

During an on-site inspection, our investigation team will fly to the required position for data capture and initial analysis of the entire blade surface, covering 360° from blade root to tip end.

Your advantages at a glance
Safe working environment
Inspection personnel operates safely from ground level instead of working at hazardous height.

Access to inaccessible areas
The integrated drone inspection system provides measurements or observations in inaccessible areas.

Reduced downtime
FORCE Technology drones can reach work height fast and efficient and begin data capture in real-time immediately.

High quality images
Our highly-skilled drone operators can fly within 5 meters of a wind turbine with dedicated equipment, producing unsurpassed image quality in great detail.

Making the inaccessible accessible
In a matter of minutes the drone can be directed to the blade tips to perform a survey that would traditionally be dangerous and time-consuming.

Dynamic surveying
Using real-time imagery streamed to the ground, the survey can be directed to investigate any potential issues while the drone is in the air, allowing focused results.

The technique and integrated applications is designed for monitoring the structural health.
Maintenance strategy

Offshore rotor blades are exposed to harsh and unpredictable weather conditions. The wind fatigue load is substantial and can cause premature damages to the blade structure.

We recommend a maintenance strategy that includes proper condition testing on critical components, e.g. blades, at regular intervals. Only proper maintenance procedures secure the long-term production efficiency and yield from offshore wind turbines. First step towards achieving all this is getting access to the blades.

Blade access

Due to unpredictable wind conditions, the blades can be difficult to access and the maintenance work troublesome. In the right conditions, there are different ways of accessing the rotor blades of an offshore wind turbine, and some of them are:

- Rope access with SPRAT certified technicians
- Cranes, cherry pickers and sky-lifts, equipped with working baskets or platforms
- Suspended platforms, hanging in wires from the nacelle housing
- Blade-guided working platforms, suspended from the nacelle housing
- Unmanned helicopter drones for visual inspection
- Crawling scanner robots, clinging to the blade surface.

Once you have access to the blades, you will be able to get an overview of potential surface erosion, structural damages and fiber waviness.

Surface erosion

A turbine operates in an air flow containing anything from dust, bugs and sand to rain droplets, sleet, snow and hail, all acting as abrasive air particles. Leading edge protection will aid in prevention of erosion, however, even the best leading edge protection is neither infallible, nor will it last forever. Periodic inspection is highly recommended to verify that the blades stay in good aerodynamic shape and condition.

Structural damages

Defects due to structural fatigue overload may occur after some years in continuous operation. You can detect and register early indications of surface cracks by using a visual control programme. A cost efficient solution to execute a safe visual survey is e.g. camera close-up inspection with unmanned helicopter drones.

If the visual survey shows any sign of damages, we recommend a thorough non-destructive testing assessment to define the extent of hidden cracks and flaws. If there is an obvious root cause, it is possible to do direct repair work, according to verified and authorised repair procedures.

Fiber waviness

A common production defect in old and new rotor blades is hidden waviness, with wrinkles and waves in the UD reinforcement layers of spar caps and girders. Due to the dynamic load on blades in operation, fatigue cracks in spar laminates may occur too early in a blade lifetime. These hidden flaws cause catastrophic blade failures, e.g. parts of blades coming to the ground.

Our well-proven ultrasonic non-destructive testing system, P-scan, lets you see beneath the blade surface. The system visualises areas with dry fiber, delamination and wrinkles. Thus, you are sure to find flaws in time, reduce failure related downtime, and ultimately the risk of catastrophic failures.
Concrete wind turbine foundations need regular assessment as they withstand enormous loads, sometimes under extreme environmental conditions.

**INSPECTION OF CONCRETE IN WIND TURBINE FOUNDATIONS**

Remaining service life of wind turbines

Onshore wind turbine foundations are massive structures. The foundation must form solid anchoring for the steel anchors that connect the tower to the foundation.

Offshore wind turbines are exposed to extreme impact from sea water, waves and wind, and they are very complicated to install, maintain and renovate. Concrete is used more or less in all types of offshore wind turbines, either as grout, which connects the monopile to the transition piece, TP, or as regular concrete foundations.

If a foundation fails, it may have serious consequences for the remaining service life of a wind turbine and entail a considerable loss on operations.

Get detailed knowledge about your structure without damaging it

The financial consequences of foundation failure are very serious. Therefore, control and testing during construction as well as operation is a necessity in order to prevent unexpected failures.

By applying non-destructive examination methods you get detailed knowledge about the structure’s condition without damaging it.

Vital data from a large area can be registered quickly and give a detailed view of the state of the structure. You may for instance use this information to minimise the number of destructive tests, which often involves core drilling to determine concrete strength or breaking up in order to know the extent of reinforcement corrosion.

**Equipment for NDT (non-destructive testing)**

- X-ray – 7.5 MeV betatron, penetrates more than 1.2 m concrete
- Geo radar systems
- Seismic methods – impact echo (IE), impulse response (IR), seismic echo (SE), spectral analysis of surface waves (SASW), multichannel analysis of surface waves (MASW)
- Ultrasound equipment as punctil, ultrasound pulse echo (UPE) & ultrasound tomography (MIRA)
- CorroMap: assess risk of corrosion & corrosion rate.

**NDT OF SUBSEA STRUCTURES**

FORCE Technology develops and operates tools for automated non-destructive testing of otherwise inaccessible areas like subsea structures whether it is monopiles or jackets. These tools are used for corrosion mapping, weld and crack inspection. The automated solutions provide accurate and precise measurement and position data of the flaws in the structure, which is easily transferred to models for calculation of stresses and remaining lifetime.

**Access the inaccessible**

Many offshore structures are almost impossible or very expensive to access for inspection when installed and in service. We have the solution to that.

The aim for the inspections are:

- Corrosion mapping of monopiles, transition pieces and jacket members
- Inspection of bracket welds for load induced cracks
- Inspection of node welds for service induced cracks
- Inspection of structural welds for service induced cracks.

**The inspection tool**

Deployment of the inspection tool is dependent on the position of the inspection area. The tool can be deployed from the topside platform, by diver or by ROV. To perform these inspections, we use the in-house developed automated ultrasonic system P-scan.

**Well proven & reliable tools**

The FORCE Technology subsea inspection system has over two decades proven to perform valuable inspection on various subsea offshore structures. The inspection system is therefore well proven and very robust and reliable.

We have an in-house development department with substantial capacity within mechanics, electronics and simulation, which allows continuous adaptation and construction of new inspection systems for a broad variety of applications.
SERVICE VESSELS FOR OFFSHORE WIND FARMS

As offshore wind turbine farms grow in numbers, the need for service vessels increases. The service vessels are used to support the construction, operation and maintenance of wind farms.

FORCE Technology offers the full range of numerical and experimental services required by builders and operators of service vessels. These services include analyses of hull forms for powering requirements, analyses of manoeuvring and dynamic positioning, seakeeping analyses, wind tunnel tests, and simulations. In the following, we present some of the more important issues to be considered in the design phase.

Powering performance

Designers and shipyards must ensure that the vessels can meet the contract specifications with a reasonable margin in terms of speed and power requirements. In order to assist the designers and shipyards in their pursuit of the best possible design solutions, we offer an advanced iterative optimisation approach based on RANS CFD.

Station keeping

Due to their specific operational requirements, the service vessels do not moor to the wind turbine foundation, but keep station by the friction against the foundation as a result of pushing against the tower by means of the vessel’s bollard pull function. In our towing tank, we can test the station keeping (bollard pull) ability against a wind turbine tower model with measurements of the axial and vertical (in ship co-ordinates) forces to evaluate the friction of the forward fender. These tests are performed in a variety of sea states (wave heights) and headings (with respect to the waves) in order to capture all possible conditions.

Seakeeping

Because of the severe environments in which they often operate, the seakeeping characteristics of the service vessels are crucial to their performance on-site. With the in-house potential radiation-diffraction code OMEGA and our analysis tool MotionLab we can calculate 6-DOF vessel motions, predict wave elevations including diffraction effects, detailed pressure fields and drift forces in a fast and cost-effective manner. Alternatively, analysis can be performed using the more sophisticated RANS CFD or physical model tests.

ULTRASONIC ON-SITE INSPECTION OF WIND TURBINE BLADES

FORCE Technology has a history of developing dedicated ultrasonic techniques to perform on-site NDT on wind turbine blades. The blades are inspected, either when mounted on the turbine, or when placed on the ground for larger inspection or repair assignments.

When suspecting integrity issues of installed blades, FORCE Technology applies non-destructive testing techniques to assess the extent of internal damages in various parts of the blade structure. Damages may be related to the production, or derive from fatigue, overload, impact or other incidents.

Since downtime directly affects production and therefore the economy of a wind turbine, it is highly important to verify the integrity of the blades. Hence, correct inspection and repairs are essential to ensure safe and reliable operation of the wind turbine during its lifespan. NDT offers a swift way of determining the extent of any defects, and with a high level of accuracy.

Typical areas of interest are:

- General thickness measurement
- Voids or delamination in the load-bearing laminates
- Wrinkles in the UD laminates
- Adhesively bonded areas such as leading edge
- Trailing edge
- Main girders and spars
- Areas with insufficient resin content (‘dry areas’); also detectable with ultrasound.

We also offer bond test inspection which – as an alternative to coin-tapping – can be utilised to detect and size lack of bond between surface coating and parent material.

On-site trailing edge inspection

One of the possible inspection options of the FORCE Technology ultrasonic P-scan system, is inspection of the trailing edge adhesive bond line for insufficient adhesion/missing adhesive between blade shells and/or internal flanges.

Our AUS-3 automated scanner is modified to perform trailing edge inspection on wind turbine blades. The scanner is placed on the upper surface of the blade, while the ultrasonic probe has been mounted to examine the trailing edge bond line on the opposite side of the blade.

On-site bond line inspection

For the inspection of installed blades, FORCE Technology has developed dedicated scanners that can be operated from work platforms and crane baskets. One of these scanners is the simple hand-held MWS-6 scanner. When coupled to the FORCE Technology P-scan system it performs fast spot checks on selected areas of the wind turbine blade.
One of the main challenges within integrity management of offshore wind turbine foundations is the constant development of corrosion protection. This has a major impact on operational security and service life, and should therefore be kept under control. We hold extensive experience within corrosion protection of offshore structures.

The corrosion protection strategy - reviewing every detail
A corrosion protection strategy should be defined during the design phase of a wind farm. All details are reviewed in order to achieve reliable operation for the entire service life (20-25 years) with minimal costly maintenance offshore.

The submerged foundation is usually protected by CP (cathodic protection) in combination with coating on the outside, whereas the internal closed compartment offers more options. The corrosion protection of other details must also be considered, such as fasteners, ladders, cranes and utility systems. We assist in defining the complete strategy based on our expertise within corrosion, failure types, CP, coatings, material selection, welding, maintenance and much more.

CP services & solutions
Many of our CP services draw from our computer software, SeaCorr™, which simulates the performance of CP systems. Among others, it identifies anode interference issues of monopile anodes, as well as proposing and verifying CP retrofit solutions.

The classic way of protecting monopiles, with anodes on the transition piece only, often proves to be inadequate, especially for uncoated structures. Interference between densely spaced anodes, combined with placing all anodes close to the surface, means that each anode does not yield the calculated current output. The result is often under-protected monopiles, which require expensive anode retrofitting. By using computer modelling, we ensure that the designers and operators get it right the first time, with large cost savings as a result.

Cathodic protection management
Proper CP management is important and necessary to stay in control, and may result in improved cost efficiency through longer inspection intervals and prevention of unforeseen corrosion damages and breakdowns. CMIS (cathodic management information system) is our own web-based data management system that allows us to share CP inspection and monitoring data with all relevant personnel.

CP Retrofit design
We perform CP retrofit design of internal surfaces within monopiles, but we also engineer the entire installation process for internal retrofitting, including elements such as the use of aluminium anodes in confined compartments that may lead to acidification.

Corrosion monitoring
A monitoring system allows continuous monitoring of the corrosion rates, corrosion potential and performance of cathodic protection systems inside the monopile foundation. Based on foundation design and risks, we assist in defining the optimum configuration.

Dissolved oxygen – a driving force for corrosion
In foundation types designed with a closed compartment, unintentional ingress of seawater is often observed. Dissolved oxygen should therefore be monitored. Systems for permanent monitoring have been supplied to several offshore wind farms. Inspection, using a specially designed measurement rack, is provided for ‘depth profiling’ of the environmental parameters in the water column inside the foundation.

Is your cathodic protection system operating correctly?
Monitoring or inspection is often requested due to uncertainties about regional and local effects on the outside, and effects from site-dependent microbiology, sediment composition and aeration of seawater on the inside.

Our advanced probes ensure that the protection criteria are met, thereby avoiding over-protection of the structure and the connected risk of hydrogen induced stress cracking (HISC). CP monitoring is based on measurement of potential, anode current and/or the actual corrosion rate of the protected steel.

Mud zone corrosion could be a problem. The mud line inside monopile foundations may experience localised corrosion due to the combination of bacterial activity and macro-galvanic elements between the oxygen-containing bulk media and the oxygen-depleted mud zone. We provide full-length corrosion coupons or real-time monitoring devices assessing such risks, including hydrogen induced stress cracking (HISC).

Record the actual corrosion rate
We offer real-time corrosion rate measurement inside monopiles. The use of well-proven probes based on electrical resistance (ER) gives an early warning of e.g. malfunction of CP, acidification or excessive seawater ingress.

Key benefits include
- Accurate measurement of current output from anodes
- Measurement of current density on structures & foundations (bare steel, coated steel and concrete)
- Detection of coating defects on structures
- Measurement of current drain to buried structures
- Reduced inspection time
IN-SERVICE INSPECTION OF WELDS ON WIND TURBINE TOWERS

With increasing demand, we have gained substantial experience in in-service inspection of welds on wind turbine towers. The most common request for weld inspection is to reveal fabrication defects or in-service induced flaws and we apply well-established NDT methods to inspect these welds.

Techniques such as Phased array, P-scan pulse echo ultrasound, Time of Flight Diffraction (ToFD), visual examination and Eddy Current, can all be applied individually or in a combination and often at the same time.

FORCE Technology’s series of remote controlled magnetic wheel scanners can all be configured to carrying multiple probe setups, which reduces the inspection time significantly. A 14-meter weld can be fully inspected in less than 10 minutes. The inspection can be conducted from a sky-climber, a mobile crane, from the ground or even by rope access technique.

The above mentioned techniques can also be applied in the fabrication stage using our specially designed FUWI scanner (fast ultrasonic weld inspection), AMS-41.

REMAINING FATIGUE LIFE ASSESSMENT OF WIND TURBINE TOWERS & FOUNDATIONS

Let us assist you in performing remaining lifetime analysis of wind turbine towers and foundations.

Different ways of determining remaining lifetime

Often, lifetime analysis of towers and foundations is focused on the welds, as they can be critical as initiation sites for fatigue cracks. Based on a stress analysis of the welds, the remaining lifetime may be estimated from current codes and standards.

If our inspection department has found defects or indications of defects in the weld, another approach for lifetime analysis is used. The approach is called ‘engineering critical assessment’ (ECA) and involves a fracture mechanics fatigue and failure assessment of the defects. ECA allows for determining the time for the defect to reach a critical size and thereby the remaining fatigue life of the component, if not repaired.

When making a remaining lifetime analysis, the following information must be available:

- The stress spectrum at the welds
- The quality of the welds
- Material mechanical properties
- The size and type of defects if applicable.

Strain gauges monitor actual stresses

The stress spectrum can be determined from known wind loads at the site, or by measuring the actual stresses close to the welds by means of strain gauges. The monitoring must be carried out over a period of time to obtain a representative set of stress data, which may be used for the fatigue life analysis.

Continuous monitoring of the actual stresses with strain gauges uncovers risks of fatigue crack initiation in the welds, which will give you the opportunity to act before a failure occurs.

FORCE Technology offers remaining lifetime analysis of the towers and foundations of wind turbines, whether it being according to fatigue curves or fracture mechanics analysis. We also have experience in setting up a complete strain gauge monitoring system for both towers and foundations.
IN SITU SURFACE TOPOGRAPHY & ROUGHNESS EVALUATION

In the wind energy sector, many components are very large and difficult to handle. In order to evaluate surface properties like roughness, wear, cracks, microstructure, fractures, corrosion attacks and surface topography, it is often necessary to make a replica casting of the surface of interest.

Replicas are usually made with fast curing polymers like two component silicone rubbers and special acetate materials developed for replica making. With these materials, it is possible on-site or in the laboratory to make a copy of the surface with a detail level down to about 0,1 µm. On-site replication has many applications such as mapping wear in mechanical parts of the nacelle power train without removing the part. It can also be used for evaluating corrosion attacks in e.g. the splash zone inside offshore wind turbines. Evaluating replicas is traditionally done in optical microscopes and takes some practice to perfect.

With FORCE Technology’s 3D confocal microscope, it is now not only possible to make a much better evaluation quantitatively, but also to make a quantitative assessment of many topographical parameters based only on a replica of the surface. The replica can be inverted for easier assessment and areas up to 170x170 mm can be imaged with a vertical resolution down to 1 nm. The practical use of this is for example to measure roughness - both traditional line based and the more accurate surface based measurements. In addition, the 3D confocal microscope can also evaluate surface cracks, surface texture and general surface topography, as well as measure surface wear and corrosion.

With 3D topography, our specialists are able to measure for example load-bearing curves for surfaces as well as a machined surface’s lubricant holding capacity. The volume of removed material from wear tracks and corrosion pits can also be evaluated quantitatively, and the texture of wear patterns can be quantified as polar curves. The software is also unique in mapping and measuring holes and particles on a surface.

Calibration of measuring equipment at FORCE Technology is based on years of experience, specialisation and international knowledge exchange. As a customer, you can expect high quality, quick service and co-operation with experts in the calibration field.

Calibration of various types of measuring equipment
FORCE Technology calibrates a large number of measuring equipment types applied in the wind energy industry, for example:
- Force measuring equipment: Transducers, weighing cells, dynamometers, lifting jacks, etc. applied for testing of rotor blades
- Torque measuring equipment: Wrenches, screwdrivers, transducers and similar, applied for testing of rotor blades and the assembling of wind turbines.

Calibration on-site & in laboratories
We offer standard calibration, verification and consultancy within the calibration field. We perform calibration on-site on customer premises, and we have fully equipped calibration laboratories where we perform laboratory calibration of measuring equipment.

In most cases, we are able to customise calibrations, consultancy and related services to your specific needs, and calibrations can take place when it is convenient for your business in order to avoid downtime.

Highest standard of calibration
As FORCE Technology is designated institute, our employees participate in national and international standardisation committees in order to keep up to date with the development. Hence, you can be assured that we apply the latest and best knowledge when calibrating your equipment, and that your needs for accredited calibration are met.

We ensure a high and well-documented quality as we are:
- Accredited by DANAK
- Co-operating with other metrology institutes in Europe
- Designated institute for force, pressure, volume and density
- Using our own well-equipped facilities and a large staff of highly experienced employees
- An independent and impartial calibration partner.

FORCE Technology
- Is accredited by DANAK
- Is designated institute in many areas, including force, pressure, flow, volume, density & viscosity
- Co-operates with other metrology institutes in Europe & participates in standardisation work.

Our calibration services cover
- Force
- Torque
- Hardness
- Pressure
- Weights & mobile weighing systems
- Material & concrete testing machines
- Temperature
- Volume
- Density & viscosity
- Gas density
- Gas flow (high pressure)
- Flow: water, gas & liquids other than water.
FORCE Technology has the leading service materials laboratory in northern Europe, working with many aspects related to materials. This includes failure and root cause analysis of a variety of components within many fields including wind power. For many years, we have offered this service worldwide.

FAILURE ANALYSIS SERVICES

FORCE Technology has the leading service materials laboratory in northern Europe, working with many aspects related to materials. This includes failure and root cause analysis of a variety of components within many fields including wind power. For many years, we have offered this service worldwide.

Failure analysis techniques were first introduced on failed aircraft components in the aviation business. The techniques are now well recognised in many industries where the costs of breakdown and production shutdown exceed the cost of repair. The wind power industry is among the industries in which every hour of downtime counts.

What is the value of failure analysis?

At the time of failure, many immediate questions arise, such as:

- What is the cause of failure?
- How do we prevent the same or similar failures?
- Who is responsible for the incident(s) leading to failure?
- Is it possible to improve the performance of future components?
- Is repair possible?

The purpose of the failure analysis is to get answers to the questions above, but the answers can only be found by applying systematic work processes. At FORCE Technology, our engineers, scientists and technicians work this way on a daily basis. Investigations and subsequent analysis results are meant to lead to the root cause, which is often referred to as ‘root cause analysis’ (RCA).

Frequent causes of failure in wind turbines

The materials in wind turbines basically consist of steel alloys, polymers and concrete systems for foundations. FORCE Technology’s departments cover all these materials.

The steels parts are used for tower skin and structure as well as for machine elements in the nacelle power train. In the latter, our metallurgists have experienced failures related to for instance fatigue and wear.

In offshore wind turbines, material degradation caused by corrosion is often observed around the splash zone. On onshore wind turbines, we have experienced brittle fractures on foundation bolts caused by hydrogen, induced during hot galvanising.

Engineering critical assessment (ECA) is a fracture mechanics fatigue and failure assessment of defects, which allows us to determine whether welding defects will grow to a critical size and result in failure. If a failure has occurred, ECA may be used to determine whether the material had sufficient mechanical properties or the structure has been overloaded.

From the result of advanced ultrasonic wing scans, our inspectors and polymer engineers have discovered delamination in wings. Such delamination may influence the wing performance and/or lead to failure.

How is failure analysis performed?

A complete failure analysis is often a multi-discipline task requiring several engineering and scientific disciplines in order to find the failure cause. We have these disciplines in-house. However, sometimes the failure analysis only requires few and simple examinations to clarify the cause and specific technical matters.

It is very important to work systematically with failure analysis. During this working process, it is also important to select the examination and testing methods judged to provide the best possible results capable of leading to the failure cause.

We use a variety of examination methods and services in failure analysis such as:

- Fully DANAK-accredited metallurgical laboratory on 3 locations
- Corrosion laboratory offering standard and customised corrosion tests
- DANAK-accredited mechanical testing facilities
- Various electron microscopy facilities (e.g. FIB-SEM, E-SEM, EDX)
- Chemical composition analysis of solid and liquid materials
- Fracture mechanical assessment/engineering critical assessment (ECA)
- Human factors psychology
- All NDT methods in-house and on-site
- Special and customised tests.

FORCE Technology performs failure analysis as a third party, and all results and conclusions are provided and documented in technical reports.
DAMAGE & BREAKDOWN

Composites & surface characterisation

ANALYSIS & DESIGN OF COMPOSITE STRUCTURES

Failure analysis in fibre reinforced plastic (FRP) composites can be challenging because the failure is often the result of a combination of factors, such as material properties, load conditions and operational environment.

Our polymer and composite experts have the skills and tools required to investigate component failures and determine the root cause. We can analyse the matrix material in order to determine the chemical composition. We can also measure the fibre weight fraction and fibre misalignment, porosity and hardness of the composite material.

Our facilities include high-resolution microscopes that allow us to look closely at the crack surface, as this often gives an indication of where in the structure the failure initiated. Using a scanning electron microscope (SEM), we can also examine the microstructure of the composite and determine whether there is debonding at the matrix-to-fibre interface.

Finite element (FE) analysis can be used to identify highly stressed areas of the structure as well as provide an indication of the maximum load before failure. This analysis is helpful in determining whether the structure failed because it was overloaded.

Design & manufacturing of composite structures

We offer a broad range of services relating to fibre reinforced plastic (FRP) composites including material selection, structural design, manufacturing processes and mechanical testing. We are ready to support the customer at any stage of product development, as well as during production.

Material selection

Our experts have knowledge of the composites market and access to state-of-the-art material databases that allow for comparing the properties of different composite materials. This allows for quickly narrowing down the range of choices, as well as identifying local suppliers. The process is also helpful with second sourcing, as it can identify alternative suppliers with similar materials.

Structural design

Composite materials are orthotropic, meaning that they exhibit different mechanical properties when loaded in different directions. It is therefore important to consider parameters such as, fibre orientation, fabric weave and thickness, and fabric stacking sequence.

One of the advantages of composite materials is that the material properties of a structure can be tailor-made to suit a specific application. This means that strength and stiffness can be added where needed, allowing for the weight of the structure to be reduced.

The size and complexity of composite structures often requires the use of finite element (FE) analysis to ensure that a structure is stiff and strong enough for the intended application. FORCE Technology’s composite specialists are experienced in FE calculations and use market-leading software to perform these calculations.

Manufacturing processes

It is important that the production parameters are controlled as tightly as possible in order to minimise variations in the composite material properties. Furthermore, a robust production process will also minimise defects and ensure that parts are produced consistently and at an acceptable level of quality.

FORCE Technology recognises that finding the right production method is critical to the success of the product and that this needs to be identified early on in the design phase to minimise production challenges and defects. Tooling and production equipment is expensive – so let us help you get it right the first time!

Mechanical testing

Mechanical testing of composite materials is important in order to ensure that the material properties used in the design are representative of the materials used in production. This is often also a requirement of certification bodies for composite materials used in load bearing structures. Our test facility can handle all standard test methods for characterising FRP. We also offer testing of adhesive joints and substructures made from composite materials.

Our facilities include two SEM instruments enabling examination of details down to a size of a few nanometres. With the added focussed ion beam facility (FIB) we are able to make subsurface structure analysis and cross section analysis of surface layers. With our ESEM option (environmental SEM) we can examine samples in a wet low vacuum atmosphere. Both instruments are equipped with energy dispersive X-ray analysis sensors, allowing analysis of the element composition of elements with atomic number >5 for an analysis volume of only 1 µm³.

These facilities are uniquely suited to make analysis of for example fracture surfaces, to determine failure modes (brittle, ductile or fatigue fractures), material contaminations and distributions of pollutants. The analysis facility makes it possible to examine material compositions and microstructure as well as surface morphology. Corrosion attacks can be evaluated and corrosion products analysed to determine the root cause. Combine this with X-ray diffraction (XRD) equipment and micro diffraction to analyse crystal structure, and we have a complete failure analysis package. The instruments are operated by highly skilled specialists with many years of experience, and combined with our staff of specialists in metalurgy, concrete, plastics and composite materials, we have the best possible package to solve any problem within failure analysis in the wind energy sector.

ADVANCED MICROSCOPY FACILITY

FORCE Technology is the leading commercial provider of scanning electron microscopy (SEM) examinations and microscopic chemical analysis in Denmark.

Micro analysis

With EDX analysis in the electron microscope (SEM) we can:

• Analyse details as small as 1 µm³
• Analyse all elements with atomic number >5
• Detect very small concentrations down to 0.1 %
• Make quantitative analyses with an accuracy of about 0.3 weight%.

The analysis is made by measuring the energy content of the characteristic X-rays produced, when the material is ionised by the high energy (10-25 keV) electrons used in the electron microscope.

Electron microscopy advantages

• High resolution down to 2-3 nm
• Very high depth of field compared to optical microscopy
• Point-and-analysis option with accurate element concentration (0.3 %)
• Superb for small particle analysis
• Automatic analysis made for many features like particle inclusions and grains
• Coating characterisation: thickness, composition
• Mapping of the distribution of elements
• Online real time interactive customer service.

SEM images of cross sections of fibre reinforced plastic composites. Left: material faults in composite material.

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Harsh weather introduces particular challenges which can increase risks because the weather windows for the operations become narrower. As a consequence, dependable dynamic positioning (DP) performance is necessary during the approach, touchdown and soft pinning. This, again, requires both training in a given operation and the ability to verify the feasibility of it.

**Train the risk down**

To support the need for training and verification, we have developed an advanced simulation model including jack-up functionality and interfaces enabling integration of DP systems. This offers crews on jack-up vessels the opportunity to train the challenging operation before performing it in real life.

As the vessel’s legs are lowered making contact with or being raised from the seabed, the environmental forces, wind, waves and current, acting on the legs change. Consequently, considerable changes occur in the motion behaviour of the vessel, the stability and the manoeuvring effectiveness, thus affecting the performance of the DP system. Such situations may benefit greatly from simulator training to reduce uncertainties and risks.

**Feasibility evaluation**

Using fast-time simulations we can perform a risk and capability/performance analysis in all kinds of weather conditions with both lowered or raised legs while manoeuvring the vessel into a position or maintaining a position.

An example could be a simulation of an approach for a jack-up vessel equipped with azimuth thrusters and bow tunnel thrusters. Initially, the legs are lowered to a short distance above the seabed while remaining at a standoff position some 400 m away from the final position.

Then the vessel is moved under DP control at a speed of approximately 0.5 knots to a soft pinning position where the legs are soft pinned. The legs are then raised a few feet, and the vessel approaches the final position at a reduced speed of 0.2 knots. As standard practice, the vessel heading is maintained constantly throughout the approach.

The simulated approach is then repeated for different wind, waves and current scenarios, leg deployment depths and water depths, thereby allowing an evaluation of the feasibility of the operation.

**An extended ECDIS chart for offshore wind farm navigation**

The traditional ECDIS chart on the bridge requires extensions with additional object layers and precise monitoring of the progress of the planned approach to the final position, e.g.:

- Vessel outlines showing both track and heading from standoff position to soft pinning position and jack-up position
- In some cases additional templates to be used in alternative weather directions
- Location and extent of sensitive or dangerous obstacles to be avoided
- Relevant features of the seabed itself such as location, shape and size of old spud-can footprints or rocks on or below the seabed.
Once on site and with the legs lowered, the final lifting sequence can commence. This is a critical moment where the value of all the preparations unfold as the spudcans penetrate the seabed.

Our advanced simulation module supports this. It includes a model of the bearing capacity versus penetration of the seabed, allowing a realistic penetration of the spudcans, horizontal forces from spudcan sliding and incidents such as rapid penetration (punch-through) and suction. The soil-bearing capacities are modelled as a function of depth and associated with the individual spudcan.

Self-propelled lift vessels provide a very efficient and cost-effective installation of offshore wind farms. However, the loads on the vessel change dramatically during the elevation and pre-loading stage.

JACKING UP TRAINING
Self-propelled vessels provide a very efficient and cost-effective installation of offshore wind farms. However, the loads on the vessel change dramatically during the elevation and pre-loading stage.

Challenging the extreme
Training not only challenges the extreme and dangerous situations, e.g. punch-through, it also covers the daily routines which can be fine-tuned, thereby building competences quickly and safely which would otherwise take years at sea.

The possibility to train the entire operation, i.e. from when the jack-up vessel arrives at the position and to the more critical elevation and pre-loading stage, reduces risks and uncertainties considerably. The operations can be planned and rehearsed and procedures may be adapted based on the experience gained.

Modelling of the seabed
Correct modelling of the seabed bearing capacity is essential but also one of the more complicated and inherently non-linear issues. The model assumes equilibrium between bearing capacity and the load carried by the legs/spudcans, which is a combination of mass, environmental loads, and buoyancy-induced loads.

The seabed is modelled with the characteristics of a real seabed including stratification, i.e. different layers with different bearing capacities. Seabed liquefaction, i.e. the slow compression of the seabed after the rig has settled is also included in the model.

The leg and spudcan mathematical models include height/depth varying forces due to wind, waves and current combined with forces from the seabed.

The mathematical models for leg and spudcan include height/depth varying forces due to wind, waves and current combined with forces from the seabed.

The vertical forces from the seabed are based on actual bearing capacity curves for the site in question, and a simplified modelling of suction is applied when the legs are retracted.

Thruster-thruster and thruster-leg/spudcan interactions (including possible shallow water effects) are all included in the advanced DEN-Mark1 manoeuvring models of the jack-up vessels.
Training and educating your personnel is an ongoing process that contributes to keeping the professional skills up to date, and at the end of the day, it will strengthen your competitive advantages.

NDT, WELDING & MATERIALS COURSES

Wind turbines are exposed to extreme weather conditions. Therefore, it is of the utmost importance that material and welding quality meet the necessary standards in order to avoid expensive and hazardous failures and breakdowns.

Visual examination of welded structures may be quite difficult without the proper skills, as the welded surface rarely gives the full picture of the quality of the weld.

FORCE Technology provides a number of planned courses in non-destructive testing, materials and welding, and since our customers often have unique demands and requirements, we also prepare and supply tailored and customer-specific courses, e.g.:

- Weldability of materials
- Welding quality control
- Repair welding
- Materials selection
- Corrosion mechanisms
- Corrosion protection, e.g. by cathodic protection or coating
- Visual weld inspection and weld defects
- Traditional and advanced NDT methods, applications and limitations
- Ultrasonic weld examination and thickness measurement.

Our instructors have a relevant theoretical education and extensive practical experience enabling them to develop and conduct tailored training programmes.

In a global world with high requirements, the use of a welding coordinator is often required and we train the co-ordinators and specialists of the future such as international welding engineers, IWE, specialists, IWTS, and technicians, IWT.

Visit forcetechnology.com for more information and course registration.

Our courses are conducted in accordance with the following standards
- NDT: EN ISO 9712 & ASNT
- Weld inspection & technology: EWF & IW examinations & issuance of diplomas
- Welding certificates according to EN and ASME.

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