Comprehensive Application of Multi-beam Sounding System and Side-scan Sonar in Scouring Detection of Underwater Structures in Offshore Wind Farms

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Abstract. In recent years, the installed capacity and power generation of offshore wind power have continued to grow rapidly, operation and maintenance testing has faced many technical challenges. Among them, the monitoring of the scour status of the underwater structure of the wind turbine and the complete basic data of the wind turbine’s full life cycle management system are of great significance to ensuring the long-term safe and stable operation of the offshore wind farm. This paper introduces the application of a combined multi-beam bathymetric system and side-scan sonar in the scour detection of underwater structures of wind farms based on an example of offshore wind farm detection in the East China Sea. The combination of the two can effectively achieve complementary advantages and obtain more detailed and accurate water depth data and underwater structure images. It provides reliable basic data support for the operation and maintenance of offshore wind farms and the establishment of life cycle management system.

1. Introduction
Compared with the traditional power generation method using heat energy, wind power generation is clean and pollution-free, which can effectively alleviate the greenhouse effect and meet the needs of national green sustainable development [1]. Offshore has the advantages of abundant wind energy resources and close to the load center of power grid. In recent years, the installed capacity and power generation of offshore wind power have been increasing rapidly. According to the statistical data released by the Global Wind Energy Council (GWEC), the total installed capacity of global offshore wind energy in 2019 exceeded 27.2gw [2]. The offshore wind farm is installed and operated in the marine environment. Compared with the onshore wind farm, its natural conditions are worse. The equipment operation is affected by wind load, geology, wave and ocean current and other complex loads. Among them, the sea current has the greatest impact on the underwater structure of offshore wind farm. Therefore, the detection of its scouring condition has become the key to the operation and maintenance guarantee [3].

At present, it is the most important means to evaluate the life cycle of underwater structures of offshore wind farms by using sonar equipment such as multi-beam sounding system and side-scan sonar. Among them, the multi-beam bathymetric system can obtain high-precision water depth data and points in the target area, and generate a three-dimensional map reflecting the geomorphic characteristics of the seabed, but it can not reflect the detailed characteristics of the seabed; Side-scan
Sonar can obtain high-resolution two-dimensional planar images of the target area, but the accuracy of location information and water depth data is low [4], both of them can not obtain comprehensive and high-precision underwater basic data.

Based on the advantages of the above two equipments, this paper proposes a detection method combined with multi-beam sounding system and side-scan sonar, which is applied to the scour detection of underwater structures in a offshore wind farm in the East China Sea. Through regular comprehensive and high-precision data acquisition and analysis, this paper aims to understand the changes of underwater structure scouring of wind farms, and provide important basic data support for the construction and improvement of life cycle management system of offshore wind farms.

2. Measuring Principle

2.1. Multi-beam Sounding System
Multi-beam Sounding System is a kind of underwater topographic survey technology with high precision, high resolution and high efficiency [5]. The system can transmit and receive the acoustic wave in a wide angle through the acoustic transmitting and receiving transducer array, and form the strip type high-density water depth data in the vertical plane perpendicular to the course, so as to draw the three-dimensional topography and landform of the seabed within a certain width strip along the route, and analyze the scouring situation according to the changes of the seabed topography around the underwater structure of the wind turbine. In this paper, the sonic 2024 broadband ultra-high resolution multi-beam sounding system from R2sonic company of the United States is used. The working frequency is 200-400kzh, the frequency is real-time and on-line adjustable. The coverage width is 10° to 160° and the ultra narrow beam of 0.5° x 1° has an ultra-high resolution of 1.25cm, and the maximum sounding range is 500m. The measurement principle of multi-beam sounding system is shown in figure 1.

2.2. Side-scan Sonar
Side-scan sonar is an active sonar, which sends out sound waves from the transducer installed in the towed fish (towed type). The echo signal image is obtained by using the acoustic reflection principle. According to the echo signal image, the seabed topography and landform are analyzed to determine the distribution of submarine structures [6]. In this paper, Edgetech 4125 side scan sonar system of American Edgetech company is used. The low frequency is 100kHz and the high frequency is 400kHz. At the same time, the beam angle is 5° to 20° downward, and the real-time online adjustment is made. The maximum range is 500m / 100kHz on one side and 150m / 400kHz on one side. The measurement principle of side-scan sonar is shown in figure 2.

![Figure 1. Principle diagram of multi-beam sounding system.](image1)

![Figure 2. Principle diagram of side-scan sonar measurent.](image2)
3. Detection Application

3.1. Project Overview
The project of a wind turbine in an offshore wind farm in the East China Sea is located in the west side of the Donghai Bridge. The water depth of the sea area is 9.9-11.9 m. It is mainly composed of soft soil foundation. The foundation type of the wind turbine is high pile concrete bearing platform, and each of them is set with a foundation [7]. The foundation of the project is divided into two sections, the lower section is a cylinder with a diameter of 14.00 m and a height of 3.00 m, and the upper section is a cone body with a diameter of 11.00 m and a height of 1.5 m; each foundation is provided with 8 steel pipe piles with a diameter of 1.70 m and a slope of 5:5:1. The operators expect that through regular inspection, the underwater structure of the wind turbine and the surrounding terrain, erosion and the exposed condition of submarine cable can be effectively mastered, which can provide scientific basis for the later maintenance of the underwater structure of offshore wind farm. In this paper, multi-beam sounding system and side-scan sonar integrated detection method are used for experimental application.

3.2. Inspection Process
Before the offshore inspection operation, the survey line shall be arranged in an appropriate way according to the operation vessel, weather, wind wave and tide current conditions at the operation site. The operation line is drawn by AutoCAD and converted into survey navigation file. The positioning parameters and recording mode are set by using the Hypack professional marine comprehensive survey navigation software, and the equipment such as depth sounder, locator and attitude sensor are connected to guide the survey ship into the measuring line position. The navigator guides the captain to correct the course and speed in real time according to the navigation software display, and starts sailing according to the designed survey line. The navigation software displays and records the measurement data such as positioning and water depth in real time.

In order to reduce the influence of ship sloshing on the quality of water depth data, the multi-beam transducer is suspended on the side of the engineering ship, and the transducer is installed in the middle of the survey ship and installed in a T-shape with a less flexible steel wire rope. Combined with high-precision optical fiber compass and motion sensor, the real-time attitude correction of multi-beam transducer is realized, and the real-time acquisition of multi beam measuring points is realized by marine positioning equipment. The integration of R2sonic2024 multi-beam sounding system and real-time dynamic underwater topographic survey are realized by using professional multi beam measurement data acquisition software. The full coverage of the target area around the wind turbine foundation can be achieved through the survey line and navigation survey.

During the detection of side-scan sonar, the towing fish is suspended at the stern of the ship by ropes to control the depth of towing fish into the water. The distance between the center of GPS antenna and the fixed bracket is calculated, and the length of towing rope is recorded to correct the position of towing fish in real time. Adjust the position and posture of the towing fish according to the on-site inspection data to avoid the interference of the ship wake. Through the survey line and navigation survey, we can master the topography and geomorphology of the submarine surface around the wind turbine foundation.

4. Data Analysis
After the completion of the detection, a series of processing, such as sound velocity profile correction and tide level correction, is carried out to obtain accurate water depth data. Blueview, Sufer, AutoCAD and other software are used to process and generate 3D point cloud map of the underwater structure of the wind turbine, the contour map of the underwater elevation of the wind turbine, and the overall 3D model map of the wind turbine, so as to display the characteristics of the underwater structure and submarine topography of the wind turbine.
It can be seen from figure 3 that the outline of the eight steel pipe piles under the water of the wind turbine is clear. Figure 4 shows that obvious scour pits are formed around the eight steel pipe piles under the water due to the change of local hydrodynamic field. The scour pits are oval in shape, with the long half axis in the east-west direction, about 34m in length, and the short half axis in the north-south direction, with a length of about 27m. At the same time, according to the scour pits and flow marks, the main flow scouring direction around the wind turbine is in the east-west direction. It can be seen from figure 5 that the elevation of the flat area around the underwater structure of the wind turbine is about -13.5m, the deepest elevation of the bottom of the scour pit is about -18.6m, and the maximum depth of the scour pit is about 5m (all based on the national elevation of 1985). It can be seen from figure 6 that there are many tubular structures suspended in the scour pit, which is speculated to be the construction waste in the process of fan installation and construction.

Figure 3. 3D point cloud diagram of the wind turbine underwater structure.

Figure 4. 3D point cloud diagram of the wind turbine underwater structure (top view).

Figure 5. Underwater elevation contour map of the wind turbine.
Figure 6. 3D image of the wind turbine underwater structure (delete pile data).

Through the side-scan sonar image data, the position, size and distribution range of the seabed structure can be obtained, and the image is more intuitive. From figure 7, we can clearly observe the morphological characteristics of the eight steel pipe piles, multiple tubular structures in the scour pit and the exposed condition of the wind turbine cable, which can be mutually verified with 3D image of the multi-beam sounding system, providing an effective supplement for data analysis.

Finally, a 3D model of the overall structure of the wind turbine as shown in figure 8 is formed based on the measured data, which can directly show the seabed scouring of the underwater structure of the wind turbine at this stage. In the later stage, through the continuous detection of the wind turbine, and processing the data from each time to form a three-dimensional image, and then compare and analyze the development and change of the scour pit around the underwater structure of the wind turbine, integrate and improve its life cycle management system, and provide the basis for the operation and maintenance of the wind farm.

Figure 7. Side-scan sonar image of the wind turbine underwater structure.
5. Conclusion and Prospect

The cooperative application of multi-beam sounding system and side-scan sonar system has achieved ideal results in underwater structure scour detection of offshore wind farm. The multi-beam bathymetric system has the characteristics of full coverage and high precision. It can not only obtain the plane position information of the wind turbine seabed foundation, but also can carry out 3D imaging through the sounding point cloud, and realize the 3D visualization. It can more directly determine the erosion of the underwater structure of the wind turbine, but the effect of reflecting the detailed characteristics of the seabed is poor. However, the side-scan sonar can present the seabed topography in the form of high-resolution 2D plane images, which can reflect the underwater structure and surrounding scour state of the wind turbine in detail, but the accuracy of location information and water depth data is insufficient. The combination of the two can effectively achieve complementary advantages, with better applicability and reliability, and can obtain more detailed and accurate water depth data and underwater structure images. It can be better applied to the scour detection engineering of offshore wind turbine underwater structure. In order to better realize the operation and maintenance management of offshore wind farm and maximize the benefits. Through the regular inspection of the underwater structure of wind turbine and data analysis and upload, the large database of wind power operation and maintenance can be improved, and the development and change of scour pit of offshore wind turbine underwater structure can be evaluated and predicted in real time, which can be integrated into the whole life cycle management system of wind turbine, providing basis for the operation and maintenance of wind farm.

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