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Abstract: Submarine cable is an important part of offshore wind power farm, so the surveying and detection of submarine cable is very necessary. Firstly, the basic characteristics of submarine cables in offshore wind power farms is introduced, three methods of submarine cable detection are analysed, conventional geophysical survey method, ROV mounted sensor method and 3D synthetic aperture sonar method. The principle of three-dimensional synthetic aperture sonar, motion compensation method and data processing method are described in detail. Taking an offshore wind power farm in Yangjiang, Guangdong Province as an example, the survey method of submarine cable is introduced based on 3D synthetic aperture sonar, and some survey images are shown. The results show that the buried depth of submarine cable could be detect by 3D synthetic aperture sonar, which is an effective means of submarine cable detection during the operation of offshore wind power farm.

Key words: Offshore Wind Power; Submarine Cable; 3D Synthetic Aperture Sonar; Buried Depth

1. Introduction

Offshore wind power generation is the use of offshore wind resources for power generation. It is a kind of green and clean energy. It has broad prospects for development under the circumstances of the gradual depletion of oil, gas and petrochemical resources, energy shortages, environmental pollution and so on. Under the dual role of industrial policy guidance and market demand drive, China's wind power industry has achieved rapid development and has become one of the few industries that can participate in international competition and obtain leading advantages. Under the clear carbon neutral target, the cumulative installed capacity of grid connected wind power in China in 2021 was 328million gigawatts, an increase of 17.3% year-on-year, and the cumulative installed capacity of offshore wind power reached 26.39 million KW, an increase of 193.6% year-on-year. The installed capacity of wind power grid connection in China has ranked first in the world for 12 consecutive years. Benefiting from the continuous introduction of offshore wind power planning and support policies in coastal areas across the country, China's offshore wind power has entered a rapid growth stage. From the perspective of new installed capacity, the new installed capacity of offshore wind power in the world in 2021 was about 13.4 GW, of which China added 10.8 GW, accounting for 80.02%, and the cumulative installed capacity of offshore wind power reached 26.39 GW, surpassing the UK to become the world's first offshore wind power market[1].

Submarine cables for offshore wind power farms include collector cables and transmission cables. The electric energy generated by multiple wind turbines is gathered to the booster station through the submarine cable of the power collection line, the voltage is increased, and then transmitted to the onshore centralized control center through the submarine cable of high voltage. The submarine cable of the power collection line is generally 35kV submarine cable, and the outgoing submarine cable varies according to the distance from the offshore wind farm to the coast. The outgoing submarine cable can choose 110kV or 220kV submarine cable according to the requirements of the offshore wind farm connecting to the power grid. There are great differences in application scenarios and performance between submarine cables and road cables. Submarine cables must have good water blocking and mechanical properties to prevent the failure of submarine cables caused by water infiltration. At the same time, good mechanical properties are also conducive to preventing ship anchoring and ocean current scouring. In addition, submarine cables also need to have the ability to prevent corrosion and marine organisms, so as to ensure that the service life meets the engineering needs.

2.The frequently-used methods of submarine cable detection

There are many submarine cable detection technologies and methods. The conventional submarine cable detection methods are mainly engineering geophysical methods on board. Marine magnetometers, multi beam, pipeline instruments, side scan sonar and other equipment are installed on board to detect the incoming cable. With the more and more extensive application of ROV, the short-range tracking with ROV as the carrier has become a more effective means of cable detection. The measurement sensors carried on ROV mainly include underwater seabed camera, TSS system (the representative equipment is TSS350), underwater sonar, etc. In addition, there are submarine cable Instruments for magnetic detection and three-dimensional synthetic aperture sonar for acoustic means.

2.1.Marine magnetometer

For conventional engineering geophysical exploration means, magnetometer can detect buried cables, while for exposed or even suspended cables, multi beam sonar and side scan sonar can be used for investigation and detection. However, at present, most submarine cables, especially buried submarine cables, need the index of burial depth, which cannot be achieved by conventional engineering geophysical exploration methods. Magnetometers can only determine the plane position of submarine cables, but it is also a simple, efficient and low-cost way for the topographic and geomorphic investigation of submarine cable route area.

2.2.TSS350

ROV can carry relevant sensors to detect the incoming line of submarine cables. The main sensors are scanning sonar, submarine cable tracking system, underwater camera system and multi beam system. TSS 350 submarine cable tracking system is commonly used to detect the buried depth of submarine cables. TSS 350 belongs to active detection. It is divided into two groups of three component probes to detect the spatial position of submarine cables. Combined with the altimeter to measure the height between TSS 350 and the seabed, the plane position and buried depth of submarine cables can be obtained[2-3].

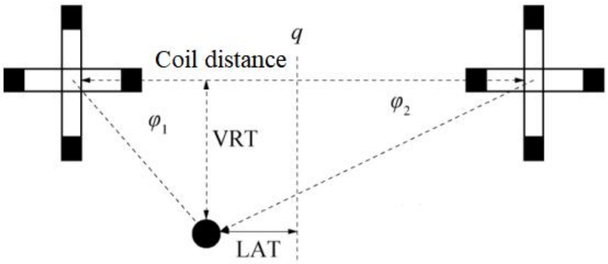


Figure 1. Principle of submarine cable detection by TSS 350

TSS 350 cable tracker is mainly composed of water surface control unit SDC, underwater electronic unit SEP, two groups (six in total) coils, altimeter, signal generator, connecting cable and mounting rod. Tss350 system provides a current signal of known frequency to the cable to be tested in advance when detecting the cable, and then detects the magnetic field distribution generated by the current signal, so as to obtain the location and buried depth of the cable.

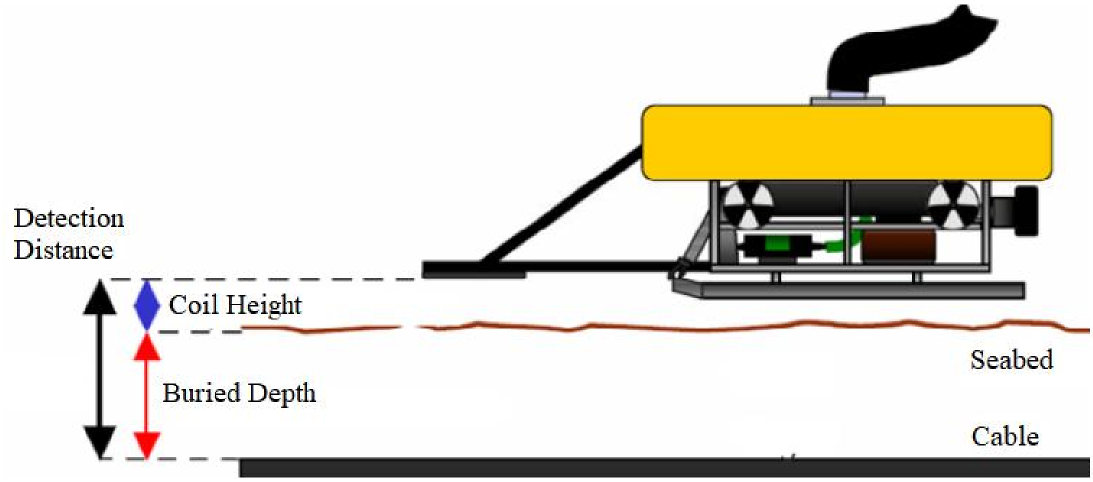


Figure 2. Surveying method of submarine cable detection by TSS 350

The cable detection method with ROV equipped sensors can detect the plane position and buried depth of the cable, and can also carry out fine investigation and measurement of the routing area. However, DP ships are required for operation, and it is difficult to operate in areas with excessive flow velocity, and the overall detection operation cost is high.

2.3.The latest profile sonar technology

3D synthetic aperture sonar is a new product emerging in recent years. It adopts area array transducers and comprehensively uses multi beam and synthetic aperture technology to realize three-dimensional high-resolution imaging in multiple directions such as distance, track and vertical track at the same time, so as to realize three-dimensional real-time imaging of ocean panorama. Using the three-dimensional imaging technology of buried pipe and cable, the three-dimensional shallow seabed profile information, the three-dimensional acoustic image of buried pipe and cable targets, as well as the continuous route and continuous depth information can be output at the same time.

3. 3D synthetic aperture sonar

The concept of synthetic aperture sonar was first proposed by raython company of the United States in the 1960s. Its basic idea is to perform aperture synthesis processing on the received signals recorded in the process of small aperture array moving along a straight line, so as to achieve the azimuth resolution effect of virtual large aperture array. It has potential application prospects in the field of high-resolution seabed imaging. The three-dimensional synthetic aperture sonar technology was first successfully tested in a pool by Griffith through interferometry. At the beginning of the 21st century, Japanese scholars Asada and others proposed multi beam synthetic aperture sonar based on multi beam sounding sonar technology, and achieved good results in the test. Harbin Engineering University and Chinese Academy of Sciences also carried out early research on 3D synthetic aperture sonar technology, and laid a certain theoretical foundation. Due to its significant advantages in three-dimensional imaging, multi beam synthetic aperture sonar makes the research and development of seabed buried target exploration technology and equipment focus on multi beam synthetic aperture sonar[4-5].

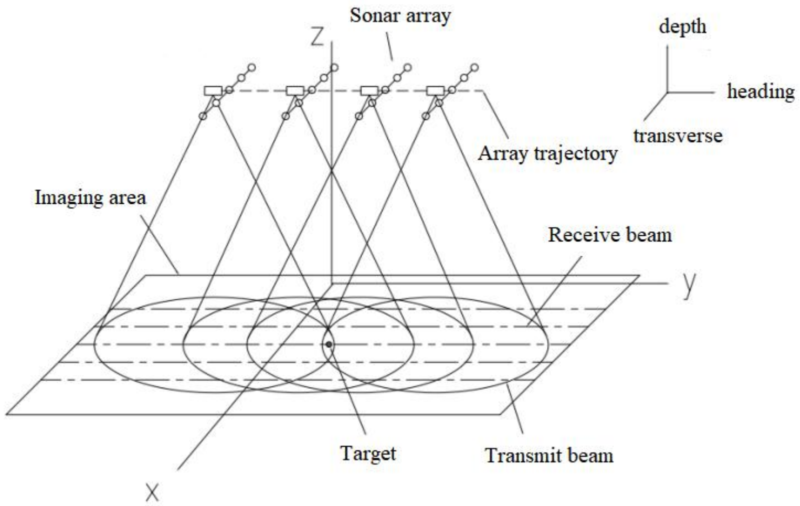


Figure 3. Principle of three-dimensional synthetic aperture technology

3.1 Motion compensation method

The carrier of 3D synthetic aperture sonar is affected by wind and waves when sailing, which will inevitably lead to the offset of motion trajectory and the swing of the carrier itself. The motion mismatch of the carrier will cause the defocus of the image. Therefore, a joint estimation method of 6 degrees of freedom based on the echo data of multiple strong point targets is proposed, and the motion deviation of 6 degrees of freedom is estimated at the same time. The signal model is shown in the figure below.

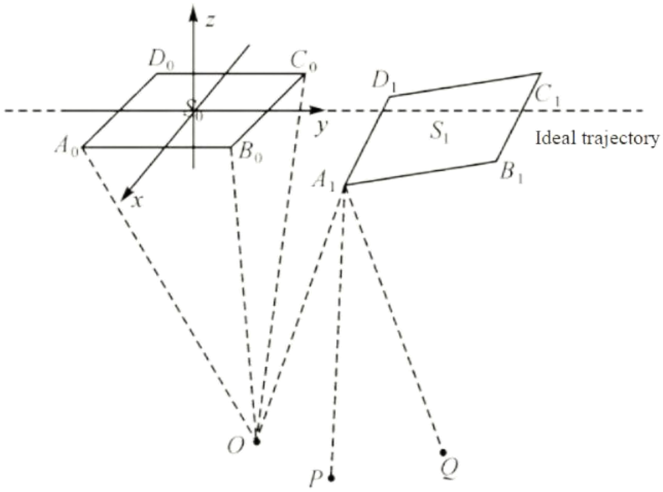
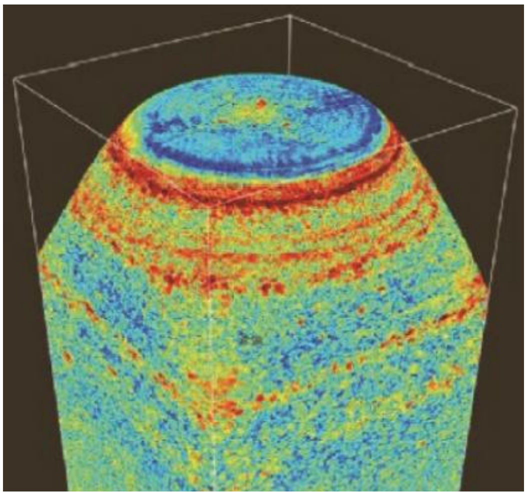


Figure 4. Schematic diagram of motion compensation

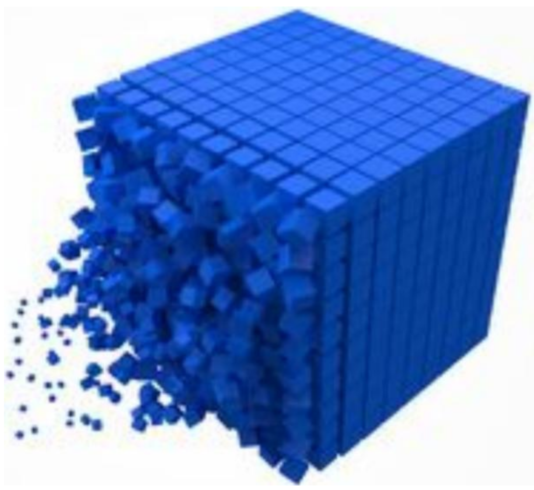
Select the array elements on the three vertices of the array, and record them as A0 (x0, Y0, Z0), B0 (x0, Y0, Z0), C0 (x0, Y0, Z0). Then calculate the coordinates of O, P and Q points according to the distance from the array element to the target point, and calculate the positions of array elements A1, B1 and C1 according to the echo received by the array at S1 position and the coordinates of O, P and Q points, so as to obtain the motion error of the carrier at this time. A clearer sonar image can be obtained by compensating the estimated motion attitude error[6].

3.2 Data process method

Data processing operations mainly include data back reading, front view, top view and right view sectioning (including surface sectioning), determining the continuous route and buried depth of submarine cables, and outputting three-dimensional and sectioned sound diagrams. The real-time three-dimensional data obtained by the three-dimensional imaging system is the full three-dimensional data from the sea bottom to below the mud surface. The basic pixel of the three-dimensional data is a cube (Fig. 5a), and the whole part from the sea bottom to below the mud surface is evenly segmented by "cube pixels" (Fig. 5b).



5a: 3D imaging data



5b: Cube pixel uniform cut

Figure 5. Long-period cumulative average scouring and silting change curves of ZD12# pier

The front view is the data profile observed from the track direction and perpendicular to the track direction. This view is similar to the traditional analysis method of high-precision deep sonar water column profile. The top view is the data section viewed from the water depth direction and parallel to the track direction. This view is similar to the analysis method of the traditional side scan view. The right view is the data section viewed from the left and right directions and parallel to the depth direction. This view is similar to the analysis method of the traditional shallow section view.

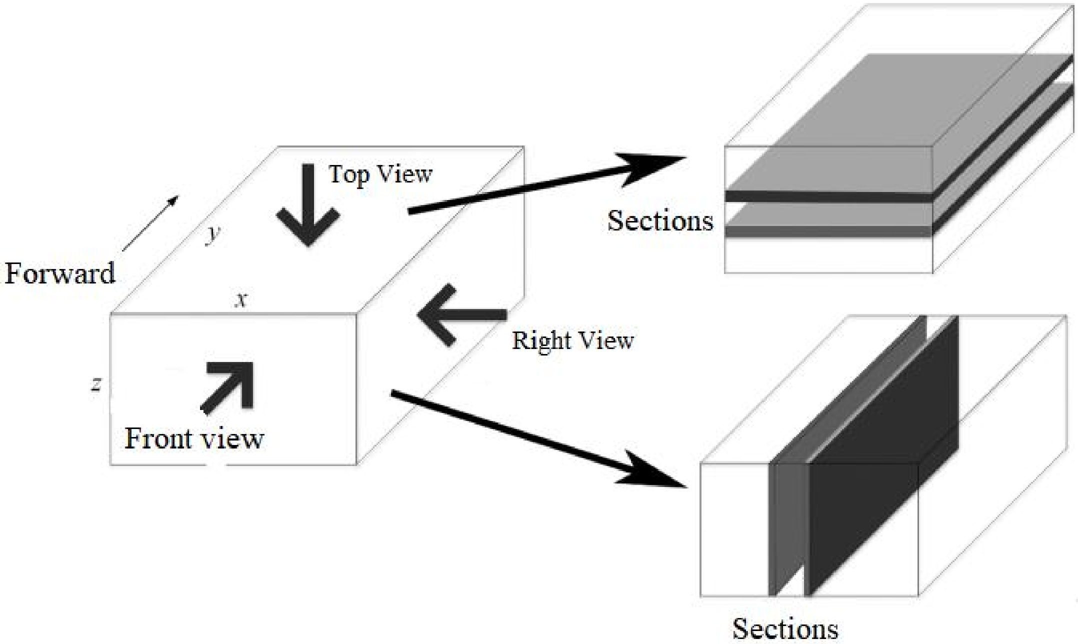


Figure 6. Schematic diagram of cutting operation

The surface view is obtained by surface cutting rather than plane cutting along the direction of the right view and the top view. Due to the influence of seabed fluctuation and the fact that the buried depth of submarine cable is not fixed and often changes, the use of curved view can better eliminate the influence of clutter within the seabed mud surface on the one hand, and better display the data and information of the target cable on the other hand.

4.Case application

4.1 Layout of offshore wind farms

The 35kV Cable of one offshore wind power farm in Yangjiang, Guangdong Province has a total of 12 circuits, and the submarine cable models include 3×70mm2、3×120mm2、3×240mm2、3×400mm2, starting from the offshore booster station, each cable is connected to multiple offshore fans, and ending at the peripheral fans of the wind farm, which is distributed radially.

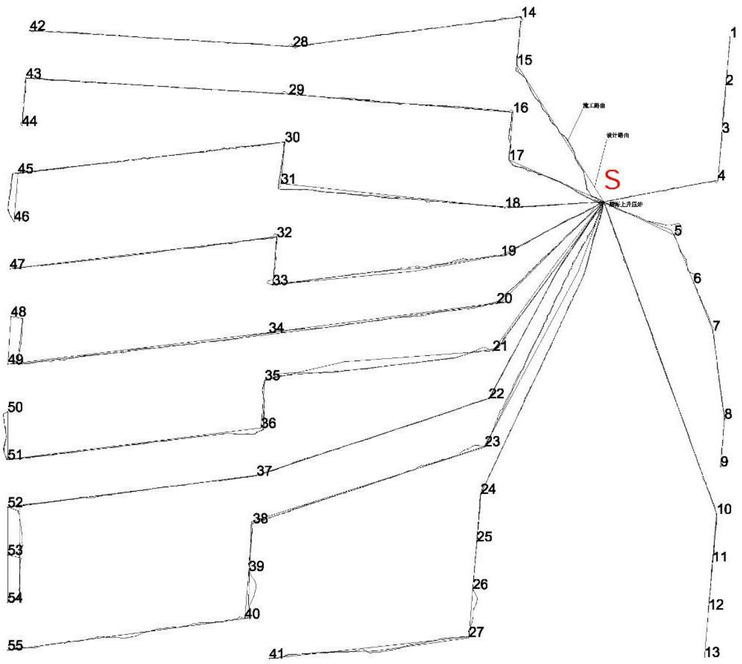


Figure 7. 35kV submarine cable layout of offshore wind farm

After the submarine cable is laid, it is necessary to carry out external inspection on the submarine cable regularly to detect the current situation of the submarine cable, including the precise water depth of the submarine cable area, submarine terrain, submarine landform, continuous direction of the submarine cable, continuous buried depth and whether it is exposed. After the detection, the investigation results will be summarized and sorted out to provide a scientific basis for the safe production, operation and maintenance of offshore wind farm fans, booster station platforms and submarine cables.

4.2 Detection and processing of sonar data

The main contents of submarine cable detection are submarine cable route positioning and submarine cable buried depth detection. Due to the influence of factors such as current scouring and seabed bottom quality, the status and location of submarine cables may change. In order to improve work efficiency, it is necessary to detect according to the submarine cable layout route map. When using three-dimensional synthetic aperture sonar for submarine cable detection, the line layout is carried out along the route direction. The deployed survey line is located at 10m, 20m, etc. on both sides of the cable route. Appropriate adjustments can be made in the actual exploration process. When the detection results capture the target submarine cable, the spacing can be adjusted to ensure the best imaging effect of the target.

When sonar detects the target submarine cable, it can determine its status, location information and burial depth information according to high-frequency side scan (seabed terrain exploration, exposed cable exploration, buried submarine cable trench trace route exploration) and low-frequency three-dimensional sonar (buried submarine cable burial depth exploration) to complete submarine cable route positioning and burial depth exploration. Seahawk B-type three-dimensional synthetic aperture sonar system is integrated with three sonars: down looking three-dimensional synthetic aperture sonar, side scan sonar and down looking multi beam sonar. The system can output the following information at the same time: submarine shallow section, three-dimensional image of seabed buried objects, cable target route, high-definition image of submarine landform and bottom sinking target, image of submarine suspended target, and high-precision submarine topographic map. The system equipment can be divided into wet end and dry end cabinets. Figure 8 shows the installation of wet end transducers on the ship side.

Figure 8. 3D synthetic aperture sonar fixed method

Select one of the #S-4-3-2-1 cable entry examples, and the cable length of this section is 2396 meters. In terms of overall landform, the water bottom of this section is relatively flat. On the side scan sonar image, the trenching trace of the cable can be seen in some sections, typical as shown in the figure below. It is obvious that the landform of trenching is very weak, and it can be seen that the effect of siltation is obvious.

Figure 9. Part of geomorphic map

The cable back siltation is in good condition, and the back siltation has almost occurred. The depth of the cable obtained by using the probe burying unit in the three-dimensional synthetic aperture sonar system is different from the trench top depth obtained by the multi beam unit, and the true buried depth of the cable is H1. However, with the gradual back siltation, the sediment will eventually cover the trench excavation, making the trench flush with the seabed surface. Therefore, more attention is paid to the difference between the cable depth and the average depth of the surrounding seabed, that is, H2. After using the three-dimensional synthetic aperture sonar to obtain the buried depth information H1 of the cable, add the difference between the current trench excavation and the surrounding seabed depth on the basis of H1, and finally obtain the information of H2 for submission. Among them, the buried depth of less than 1 meter is 66 meters, the buried depth range of 1-2 meters is 36 meters, the buried depth range of 2-2.5 meters is 648 meters, and the buried depth of more than 2.5 meters is 1646 meters.

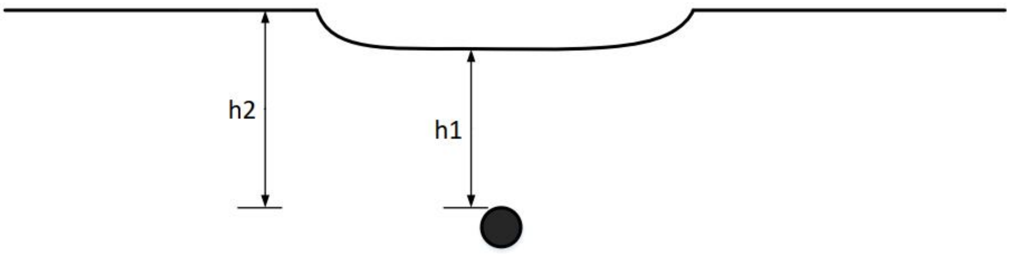


Figure 10. Description of buried depth of buried cable

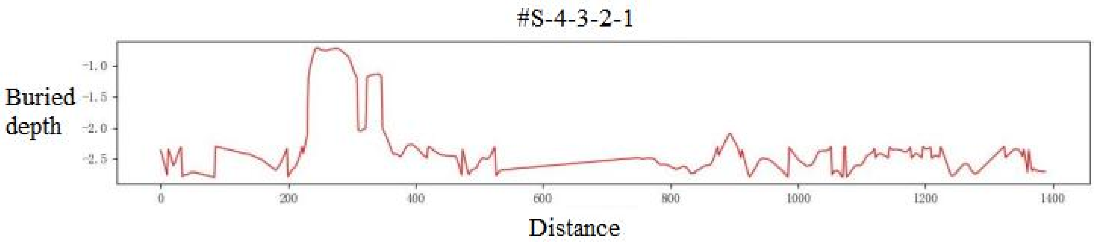


Figure 11. Schematic diagram of buried depth of some cables

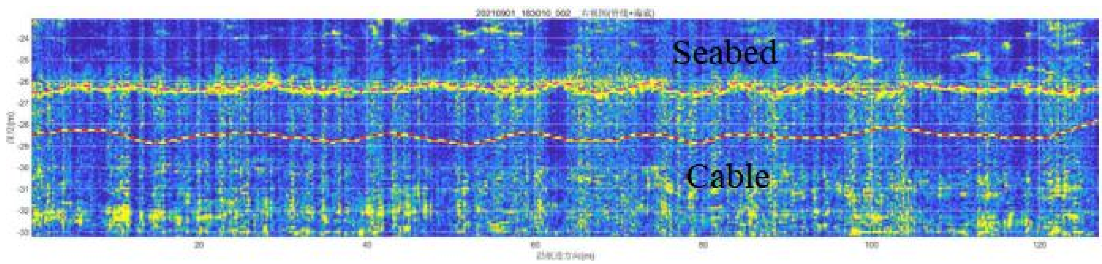


Figure 12. Typical right view of submarine cable

5.Conclusion

Based on the actual needs of offshore wind power submarine cable detection, this paper compares three methods of submarine cable detection, and puts forward the optimal scheme - three-dimensional synthetic aperture sonar method, considering the operation cost and efficiency. Taking an offshore wind farm in Yangjiang, Guangdong Province as an example, the status of submarine cable trench and buried cable can be clearly seen by using submarine Eagle B-type 3D synthetic aperture sonar to detect the incoming line of a certain section of submarine cable, and the buried depth of submarine cable in the routing section can be obtained, which provides an important reference for the safe operation of submarine cable.

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