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Application and prospect of 3D Synthetic Aperture Sonar System in submarine pipeline verification in Guangdong-Hong Kong-Macao Greater Bay Area

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Abstract

The 3D Synthetic Aperture Sonar System is one of the world's most advanced equipment with high resolution in the exploration of submarine buried target .During the 14th Five-Year Plan period, submarine pipeline verification work has been conducted in the Guangdong-Hong Kong-Macao Greater Bay Area using different equipment in two depth zones: shallow areas (less than 10 meters) and deep areas (greater than 10 meters).Traditional survey equipment such as sub-bottom profilers, magnetometers, and side-scan sonars were used for the shallow areas, while new equipment like 3D Synthetic Aperture Sonar Systems was used for the deep areas.By analyzing the results of submarine pipeline verification, this paper illustrates the advantages of the 3D Synthetic Aperture Sonar System in solving the integrated 3D surveying of water bodies, seabeds and sub-bottom.

Keywords

3DSynthetic Aperture Sonar; submarine pipeline; burying target detection.

1. Foreword

Submarine pipeline is an important underwater infrastructure for long-distance communication, power supply, oil transmission and gas transmission.For example, the undersea fiber optic cable, which is an important communication infrastructure in the world, is responsible for more than 95% of the transnational data transmission in the world[1].In recent years, with the development and comprehensive utilization of marine resources in China, the demand of laying submarine communication cable, submarine power cable, water and gas pipelines between islands is also increasing[2].However, the submarine pipelines are mostly concentrated in the shallow water area of the continental shelf, which is also the area where the failure point of the submarine pipelines occurs.The most direct reason is Marine fishery and maritime shipping.At the same time, the water depth of the coastal area is shallow and the hydrodynamic effect is strong.The long-term alternating erosion of ocean current and tidal current is easy to erode the submarine pipe road, resulting in the gradual exposure, suspension and plane displacement of the pipeline[3].Therefore, it is of great significance to carry out submarine pipeline verification and find out the buried and service conditions of submarine pipelines to improve the safety of offshore submarine pipelines and optimize the future buried path of submarine pipelines.

currently, The marine pipeline detection mainly adopts magnetic detection, multi-beam sonar detection, shallow formation profile detection and synthetic aperture sonar detection[4], For example, Zhao Zhanning uses magnetometer, multi-beam sonar, shallow formation profiler and other methods to detect the proposed regional stratigraphic structure and the layout of underground facilities of offshore wind farms, To avoid construction activities from damaging submarine oil and gas pipelines or transmission lines[5]; CAI Xuan and other scholars proposed

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the comprehensive detection method of submarine cable using multi-beam, side sweep sonar, shallow formation profile, magnetometer, etc., And successfully applied in Jiangsu Dafeng offshore wind power submarine transmission cable detection[6]; Dong Yujuan and other scholars, through the comprehensive application of various detection methods, To test a sea water pipeline in Zhoushan, In order to understand the location, buried depth of the seabed pipeline and the change of the seabed topography near the pipeline in a sea area of Zhoushan[7].In addition, Song Shuai, xiao-hua Chen scholars also from the equipment use principle, detection effect, cost of several Marine detection equipment analysis compared[8-14], shows that 3D synthetic aperture sonar system has the ability to explore suspension, sink and buried target, not only can obtain the target 3D images and buried depth information, also has a high resolution of submarine imaging ability, can solve the problem of deep sea area of a large range, large area survey.

The concept of synthetic aperture sonar was first proposed by Raython in the US in the 1960s.At present, The domestic commercial 3D synthetic aperture sonar is mainly designed and produced for the China Science and Technology Exploration Ocean Science and Technology Co. , Ltd. [2,10].3D synthetic aperture sonar system can achieve high precision, high resolution and high efficient detection for underwater buried targets.Compared with traditional acoustic detection equipment such as shallow formation profile instrument, it can detect smaller line targets; compared with the long distance, high resolution and the comprehensive application of shallow surface analyzer, magnetometer and side sweep sonar, the work efficiency is higher, and the error rate is lower.

This paper is based on a large bay area of Guangdong submarine pipeline verification work, in the area respectively using side sweep sonar, shallow formation profile instrument, Marine magnetometer, 3D synthetic aperture sonar system to carry out the international cable, natural gas pipeline, oil and gas mixed pipeline and submarine cable pipeline location and depth verification, to illustrate the 3D synthetic aperture sonar system to carry out the advantages of seabed features survey.

2. Principle of 3D synthetic aperture sonar system

The 3D synthetic aperture sonar system adopts a number of technologies such as multi-frequency, adaptive aperture and three-dimensional synthetic aperture, and integrates three sonar units, including 3D synthetic aperture sonar, downvision multi-beam sonar and side view sonar, to achieve the exploration capability of suspension, sink and buried targets.

2.1. Multi-frequency Sonar Technology

Multi-frequency sonar technology mainly plays the characteristics of different frequency sound waves to realize the comprehensive detection capability of suspended, submerged and buried targets.That is, the high frequency sound wave has short wavelength, fine target imaging, but no penetration ability, cannot detect the buried target; the low frequency sound wave has the strongest detection ability, can meet the detection ability of suspended, submerged and buried target, but the target imaging is less fine than the high frequency sound wave.

In order to solve the contradiction between burial capability and resolution capability, the integrated 3D synthetic aperture sonar in real-time Marine panoramic acoustic imaging system works in low frequency band, and uses the synthetic aperture technology to improve the resolution capability of targets as much as possible.The integrated down-view multi-beam sonar and side-view adaptive aperture sonar in high frequency band, can obtain high resolution results of submarine topography and landform and seabed target.Using the above various frequency band sonar configuration, taking into account the actual needs of exploration and high resolution.

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2.2. Adaptive Aperture Technique

The adaptive aperture technology can intelligently switch between solid aperture and synthetic aperture, in which the real aperture is the traditional lateral imaging.It uses pulse compression technology in the vertical track direction to realize a constant high line resolution, extremely narrow beam with long array and high frequency in the track direction, and the basic principle of synthetic aperture sonar is to use small aperture matrix to make uniform linear motion to form a virtual large aperture matrix, transmit and receive the echo signal in the motion trajectory, and coherently process echo signals at different positions, so as to obtain a high resolution. However, when the platform is too fast, frame leakage occurs in a synthetic aperture length, leading to target defocus.

Adaptive aperture technology is able to real-time tracking platform speed, and in order to avoid speed beating error, using the Kalman filter technology to filter and estimate the platform speed, when the platform speed meet the synthetic aperture processing conditions, using the synthetic aperture algorithm, when the platform speed does not meet the synthetic aperture processing conditions, use the solid aperture algorithm.

2.3. The 3D Synthetic Aperture Technique

3D synthetic aperture technology uses a combination of multiple beam and synthetic aperture sonar technology, using synthetic aperture technology in the track direction, and using multi-beam technology in the vertical plane of the vertical track direction.The organic combination of the two technologies can overcome the problems of "consistent design of multi-channel receiver" and "overcome the problems of" parallel processing of large-scale data ", and realize the 3D real-time imaging of ocean panorama.

3. Submarine pipeline verification case

This paper studies the verification of submarine pipelines in the Guangdong-Hong Kong-Macao Greater Bay Area. The verification area is divided into two sea areas: 10 meters deep and 10 meters shallow. Traditional exploration equipment and 3D synthetic aperture sonar system are used to carry out relevant exploration, and the detection data are compared and analyzed.

3.1. At 10 meters deep in the sea

This area is detected with A2 series 3D synthetic aperture sonar, and the ship side is fixed when operation at sea. The measuring line layout takes the existing line as the center line, Lay one measuring line parallel to each side of the pipeline direction, The spacing of 2 measuring lines is 30 meters (Figure 1), And ensure 20% overlap between line and line, By having ships sailing back and forth along both sides of the line, Using the real-time synchronous working mode of the three sonar units in the 3D synthetic aperture sonar system, To achieve real-time synchronous detection of suspended, submerged and buried targets, Real-time synchronous mapping of topography, landform and three-dimensional shallow formation imaging (Figure 2), The actual location and buried depth of the pipeline are determined, And through the layout of the two measuring lines, Ensure the full coverage measurement of the equipment measurement blind area and the pipeline deviation point.

In the actual verification process, in order to ensure the accuracy of the actual location and direction of the target pipeline, the three-dimensional synthetic aperture sonar first determines the target pipeline with low precision, and then takes the precision sweep to determine the position, the height, the nature of the target.

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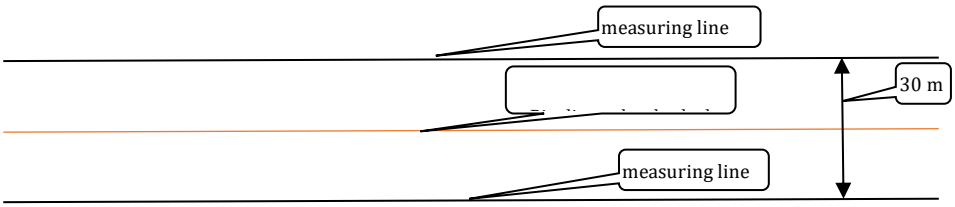

Figure 1 Example of survey lines of multi-bands 3D Synthetic Aperture Sonar

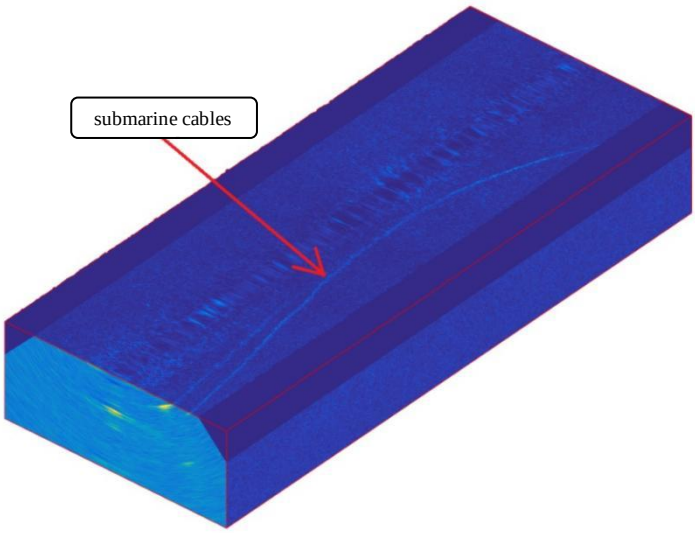

Figure 2 Real-time 3D imaging of submarine cables

According to the sonar image data acquired on site, the pipeline location information of the shallow burial in the soft soil can be obtained after interpretation and analysis, as shown in Figure 3.

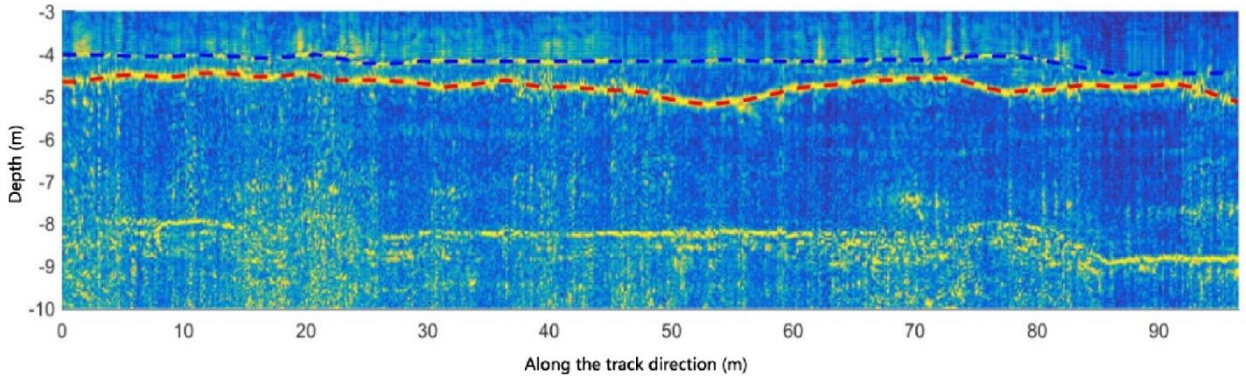

Figure 3 Right view of a submarine cable (blue line is seabed line, red line is Buried submarine cable)

3.2. At 10 meters in shallow waters

In this area, EdgeTech 2000DSS and EdgeTech 4200 side sweep shallow profile combination system, G-882 cesium optical pump magnetometer and other traditional means are used for verification.During offshore operation, the two-in-one system of magnetometer and side sweep shallow section is installed with tail towing, and the installation of shallow stratum profinstrument is fixed on the ship side.In terms of measuring wiring, in order to ensure that the pipelines from the original setting position can be detected, the length of the measuring line layout is 500 meters and the spacing is 25 meters (Figure 4).By going across the pipeline, the vessel uses the side scan sonar (Figure 5), determines the location of the pipe route according

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to the interpretation of the side scan sonar; and uses the shallow formation profile and magnetic ometer to obtain the buried pipe route, including the points with abnormal reflected wave (Figure 6) and abnormal magnetic information (Figure 7), namely the pipeline location and buried depth.

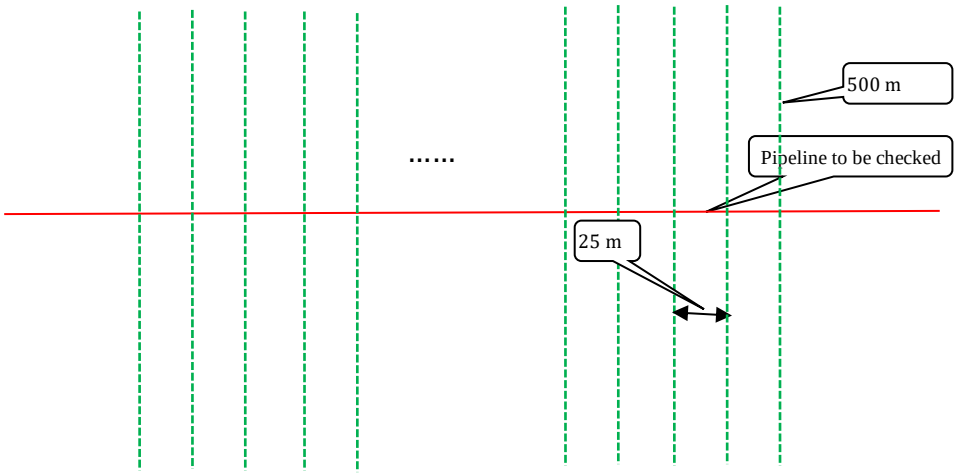

Figure 4 Example of survey lines of area with water depth less than 10 m

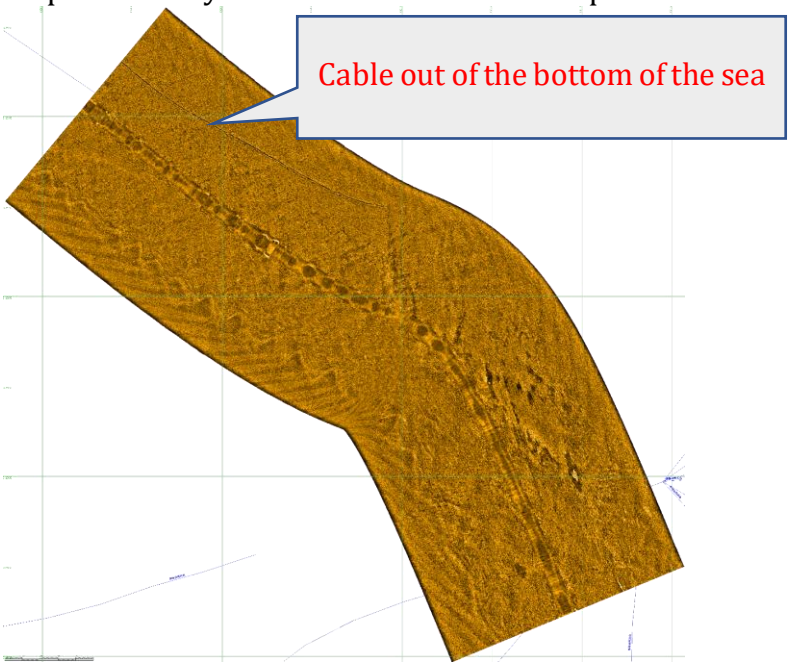

Figure 5 Image of exposed cables (Collected by side scan sonar)

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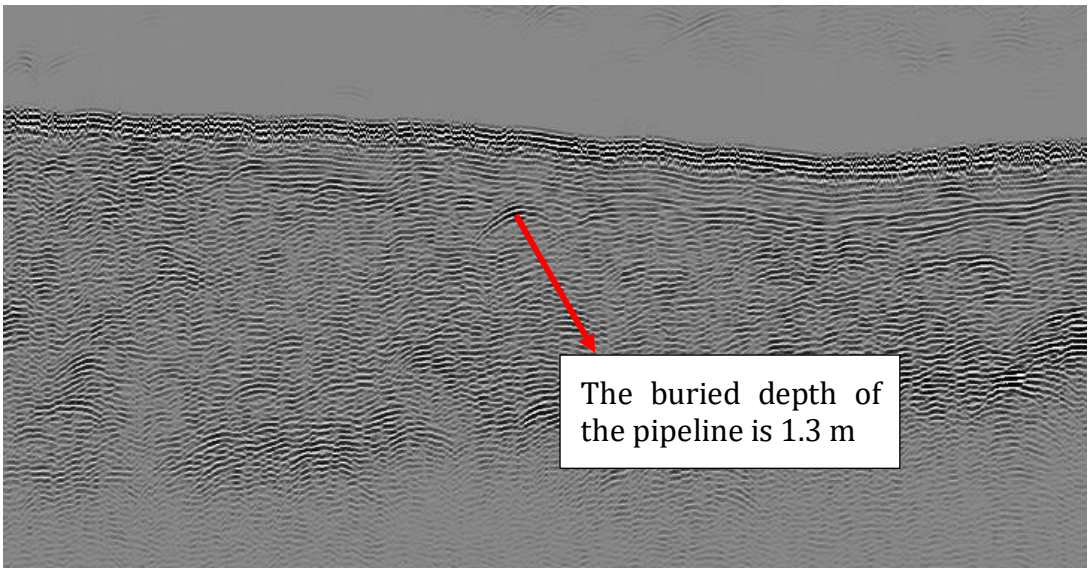

Figure 6 Depth data revealed by sub-bottom profiler

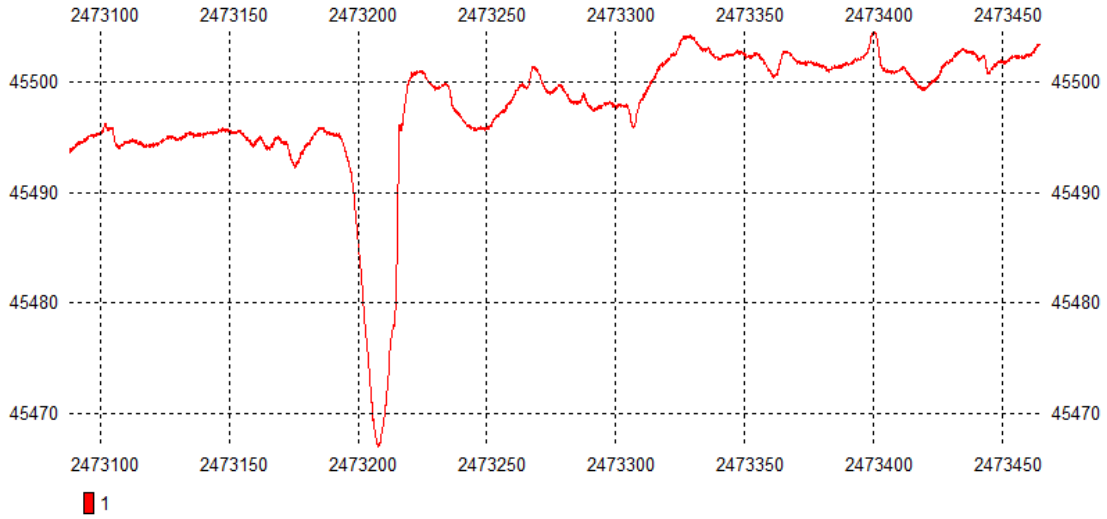

Figure 7 Magnetometers obtains information about single-point magnetic anomalies

4. Analysis and Summary

There are a total of 54 pipelines inspected, including 6 pipelines, 28 cables and 15 optical cables.The length of the verification pipeline is about 1,537 kilometers, of which 10 meters is about 368 kilometers and 10 meters is about 1,169 kilometers.

Most of the six pipelines verified are in the laying state, which can be clearly found by side scanning sonar on the seabed surface, and some are buried in shallow state, which is speculated to be the seabed sediment with a shallow burial depth, generally about 1-3 meters, and are basically buried in the landing section, the crossing section and the three links, and are protected by riprap.

The 28 cables checked are basically in a buried state, with a buried depth of about 1-2 meters.Generally, only some cables are exposed to the seabed near the booster station.

Of the 15 optical cables verified, two abandoned optical cables were not found at the site, and the remaining 13 were buried in the whole process.Among them, the four optical cables laid in the past five years are relatively accurate, and most sections can be detected, with the buried depth ranging from 0.5m to 4m.Nine optical cables that have been laid for 10-25 years have

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been repaired for many times, with partial deviation of the original optical cable.The buried depth of each optical cable ranges from 0.3-4 meters.

The working mode of the real-time synchronous operation of the 3D synthetic aperture sonar system makes it have obvious advantages compared with the traditional equipment in terms of continuity and efficiency.

In terms of continuity, on the one hand, the 3D synthetic aperture sonar system is not affected by the pipeline burial, and can detect and obtain the continuous suspension, submerged and buried pipeline data, solving the problem that the side scan sonar can only obtain the suspended and submerged pipeline data; on the other hand, the 3D synthetic aperture sonar system can detect and obtain the buried depth data, solving the problems of only single point data for the magnetometer and the small opening angle of the shallow formation profile.This is conducive to a comprehensive understanding and analysis of special situations such as turning points, overlapping points and maintenance points on the submarine pipeline.

In terms of high efficiency, on the one hand, in terms of investigation efficiency, this survey used traditional equipment to check the 368 km pipeline for 10 days, and only obtained the point data more than 25 meters apart, and used the 3D synthetic aperture sonar system to check the 1169 km pipeline for 9 days, that is, all the point data on the pipeline were obtained.On the other hand, after the investigation of data processing, the data of the three devices should be matched and integrated; the data of the points can be integrated during the data acquisition process, by importing the auxiliary information such as tide level and draft correction. Therefore, the data processing and output efficiency of 3D synthetic aperture sonar system is faster and the error rate is lower.

Through a large bay area of Guangdong submarine pipeline verification 10 meters deep, 10 meters to shallow two areas using different survey equipment, 3D synthetic aperture sonar system integrated use of multiple frequency, adaptive aperture and three-dimensional synthetic aperture technology, integrated three-dimensional synthetic aperture, multiple beam and lateral view adaptive aperture imaging three subsystems, realized the suspension, sink and buried target real-time synchronous detection, realize the terrain, landform and three-dimensional shallow formation imaging real-time synchronous figure, effectively solve the water, seabed and shallow strata information stereo synchronous acquisition problem.However, in this verification work, the A-type 3D synthetic aperture sonar system needs to be carried by large ships because of its large size.Therefore, it still needs to rely on traditional equipment for survey in areas inaccessible to large ships such as shallow waters and wind farms.

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