Domestic Expendable Conductivity-Temperature-Depth Profilers and Sea Trail

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Abstract. This paper introduces the composition, function, technical performance, and measurement principle of Expendable Conductivity-Temperature-Depth (XCTD) Profiler, as well as the key technical problems has solved, and compares the technical parameters of domestic and foreign XCTD profilers used to deep sea. Based on comparative marine tests of SEB19 plus CTD and domestic XCTD profilers, it is found that the coefficients of correlation of both domestic and foreign XCTD profilers to CTD is above 0.999 and their measurement errors are almost the same in terms of single-profile measurement results, which leads to the conclusion that domestic XCTD profilers are comparable to similar products made in the US and other countries in both measurement accuracy and reliability.

Keywords: XCTD profiler; key technology; temperature; conductivity.

1. Introduction

Expendable Conductivity-Temperature-Depth(XCTD) Profiler is an advanced instrument for measuring the elements of dynamic marine environment. It can quickly and covertly acquire underwater temperature and conductivity data when the ship is moving, and derive salinity, density, and sound velocity profile data. Fast, cost-effective, easy to operate, and covert in measurement, it can quickly acquire hydrological data from large sea areas and provide advanced measurement means for marine investigation, scientific research and military application. So far, Lockheed Martin Sippican of the US and TSK of Japan have been world-leading manufacturers of XCTD profilers.

The National Ocean Technology Center (NOTC) of China has been devoted to the study of XCTD profilers since 2000. After years of technical research it has mastered all the core technologies of such profilers and possessed the capacity of commercial production. In this process, it has also formed a strong R&D team for the development of expendable temperature-conductivity-sound-flow profiling technologies. At present, NOTC can provide a variety of XCTD products, and is committed to the development of new models to meet the needs of different customers.

This paper introduces the composition, function, technical performance, and measurement principle of NOTC XCTD Profiler, as well as the key technical problems it has solved. The paper also introduces NOTC's research and development of XCTD profilers based on laboratory and marine tests.

2. Composition and function

2.1 Product Composition and Function

XCTD profiler is mainly composed of XCTD measurement probe, launching device, data receiving and processing unit. The XCTD profiler developed by NOTC is shown in Fig. 1. XCTD probe is a disposable instrument with low cost for comprehensive application. The workflow of XCTD profiler is as follows: the probe is launched into the water by the launching device located at the stern (or either side of the ship); after entering the water, the probe begins to measure the temperature and conductivity of seawater, and the measurement data are transmitted to the data receiving and processing unit in real time as the probe sinks in the water. No matter the ship is moving or is in a stationary state, the XCTD measurement probe can be launched into water to acquire the data of seawater temperature and conductivity profiles in real time, from which the data of salinity, density, and sound profiles can be derived.

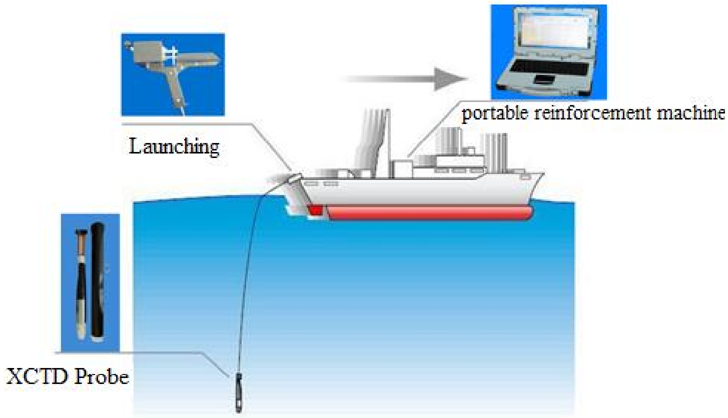

Fig. 1 Composition of the XCTD profiler developed

As the main body of the XCTD profiling system, the measurement probe (XCTD probe) mainly consists of temperature and conductivity sensors, high-strength thin wires, and casing. It is mainly used to acquire temperature and conductivity data. The launching device is a relatively independent component of the XCTD profiler. Its function is to put the measurement probe into seawater. When the probe works under water, signals are transmitted between the probe and the integrated processor to complete data communication. Mainly including a data acquisition unit and data processing software, the data receiving and processing unit receives real-time measurement data of the XCTD probe and processes the received data. The data acquisition unit and data processing software can either be placed in the data acquisition box and the computer, or be integrated into the same human-computer interaction terminal. NOTC has designed three installation and integration modes for the data receiving and processing unit of the XCTD profiler, by which the unit can be installed in the portable collection box, in the portable reinforcement machine, or in the wall-mounted reinforcement machine. These three designs basically cover all the requirements of current ship-borne XCTD profiling applications, and users can choose any one of them according to actual needs.

The function of the software is to judge the probe’s water-entry signal, record, display, analyze, and process temperature and conductivity profile data in a real-time manner, and show how such data change with depth. The data acquisition and processing software can be integrated into the portable reinforcement machine or the wall-mounted reinforcement machine. When it is integrated into the portable collection box, it needs to be used in combination with a human-computer interaction terminal equipped with an operating system that is no lower than Windows XP. The real-time data processing software integrates XCTD data acquisition and processing functions. The software detects the probe’s water entry, displays, stores, and replays temperature and conductivity profile data in real time. It also has the function of calculating derivative quantities such as salinity, density, and sound velocity of seawater.

2.2 Technical Performance

Over the past decade, with the support of the National 863 Program, the Public Marine Interest Project, the Global Change and Air-Sea Interaction Project, and other projects, NOTC has carried out comprehensive research on XCTD profiling, and many of the research results have bridged China’s gaps in the field and reached internationally advanced level. Some of the technical indicators of current XCTD profilers developed by NOTC in Table 1.

Table 1. Technical indicators of NOTC XCTD profilers used to deep sea

Name	Maximum navigational speed (kn)	Maximum working depth (m)	Error of depth measurement	Range of temperature measurement (℃)	Error of temperature measurement (℃)	Range of conductivity measurement (mS/cm)	Error of conductivity measurement (mS/cm)
NOTC XCT-3	6	1800	±2%FS	-2～35	±0.02	2～65	±0.03

2.3 Principle of Measurement

The core of temperature measurement is single-chip computer, AD converter and negative temperature coefficient thermistor, where high precision measurement of seawater temperature is realized with the support of precise operational amplifier circuit, reference source and software and hardware filtering technology. An inductive conductivity sensor is used for conductivity measurement, which is mainly composed of magnetic loop coil and conductance cell. The principle of inductive conductivity measurement is shown in Fig. 2.

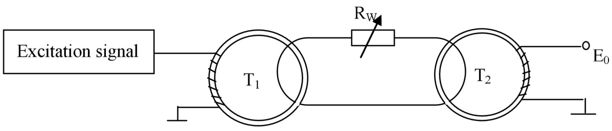

Fig. 2 Diagram of the principle of inductive measurement of electrical conductivity

This is made up of two coaxial coils T1 and T2. The excitation signal is added to the primary winding of the T1. The seawater constitutes a single-turn circuit that couples T1 with T2, and its equivalent resistance is Rw. When an excitation signal is added to the primary winding of T1, an electrical current is induced in the single-turn circuit of seawater. The current then induces an electromotive force E0 in the secondary winding T2, and the magnitude of E0 depends on the strength of current in the single-turn circuit of seawater, that is, the conductivity of seawater. Therefore, as long as the value of E0 is measured, the conductivity of seawater can be measured through scaling.

3. Key Technologies Solved

After years of technical research, NOTC has mastered some core technologies of XCTD profilers and formed a strong R&D team for the development of expendable temperature-conductivity-sound-flow profiling technologies. NOTC has solved the following key technologies:

3.1 Sensor Measurement Technology

The XCTD sensor unit includes a temperature sensor and a conductivity sensor. The former uses thermistors as sensing elements and realizes fast and reliable measurement of temperature by solving the key technology of properly addressing the contradiction between rapid response and service life. The latter's key technology is to ensure the accuracy, stability, and reliability of conductivity measurement. Aiming at the two main problems of sensor drift correction and fast acquisition and processing of signals, it adopts the dynamic automatic calibration technology suitable for rapid measurement of ocean parameters.

3.2 Technology of Data Transmission through Long Thin Wires

XCTD profiler's real-time data transmission is carried out over a long distance (3000m) through a thin wire wound on a spool in the probe. Underwater data transmission is the key to rapid measurement of the XCTD field, and such measurement requires fast, reliable, anti-jamming, long-distance transmission of signals while the long thin wires are under a tensile state in seawater. NOTC has mastered the technology of underwater communication through long thin wires, ensuring the reliable operation of XCTD profilers.

3.3 Depth Estimation Technology

Depth data of XCTD profilers are obtained not by pressure sensors, but by calculating the probe's descending speed in water using a certain formula. The descending speed formula is only related to the time passed since the probe enters water, the moment of which is taken as the origin of time. According to the time passed, the probe's present descending speed can be obtained and its depth in water can be obtained through integration. The depth calculation formula is induced and corrected through sea tests, and the depth calculation results are corrected based on a comparison with the fixed-point CTD data obtained in sea tests.

4. Tests

4.1 Verification Test

In order to check the probe's accuracy of temperature and conductivity measurements, two NOTC-developed XCTD probes were randomly selected in October 2021 and November 2022, respectively, for verification tests at the National Center of Ocean Standards and Metrology (a third-party inspection agency).Test results show that the technical performance of XCTD profilers used to deep sea has reached or approached the technical level of similar foreign products. A comparison of technical indicators between domestic and foreign XCTD profilers is shown in Table 2.

Table 2. Comparison of technical indicators between domestic and foreign XCTD profilers

Table 3. Data comparison between XCTD and SEB19 plus CTD

Parameter	Manufacturer	(TSK)	(NOTC)
	Technical indicator	Foreign XCTD	Domestic XCTD
Temperature	Measurement range	-2~35℃	-2~35℃
	Measurement error	±0.02 ℃	±0.02 ℃
	Measurement resolution	0.01℃	0.01℃
Conductivity	Measurement range	0～60 mS/cm	2～65 mS/cm
	Measurement error	±0.03 mS/cm	±0.03mS/cm
	Measurement resolution	0.017 mS/cm	0.017 mS/cm

Note: 1. Foreign XCTD technical indicators are cited from reference [2].

4.2 Sea Test

Since the XCTD profiler was developed, dozens of sea launch tests and more than one thousand probes have been launched. In 2022 alone, six domestic institutions used the NOTC-developed XCTD profilers satisfactorily, proving that the data quality is good, and the overall technical performance can meet the requirements of rapid, accurate, reliable measurement in complex sea areas when the ship is in the moving state. [4~5]Taking the survey and application voyage of the Institute of Oceanography of the Chinese Academy of Sciences as an example, twelve NOTC-developed XCT-3 probes and several XCTD-4 probes developed by TSK, a foreign company, were put to use on this voyage. In particular, Five XCT-3 probes and one XCTD-4 probe were placed at fixed points to perform measurement in comparison with SEB19 plus CTD of the United States. The results of comparative measurement showed that the data obtained from different probes were basically the same. Fig. 3 shows the measurement curve of a typical XCT-3probe and that of the American SEB19 plus CTD probe.

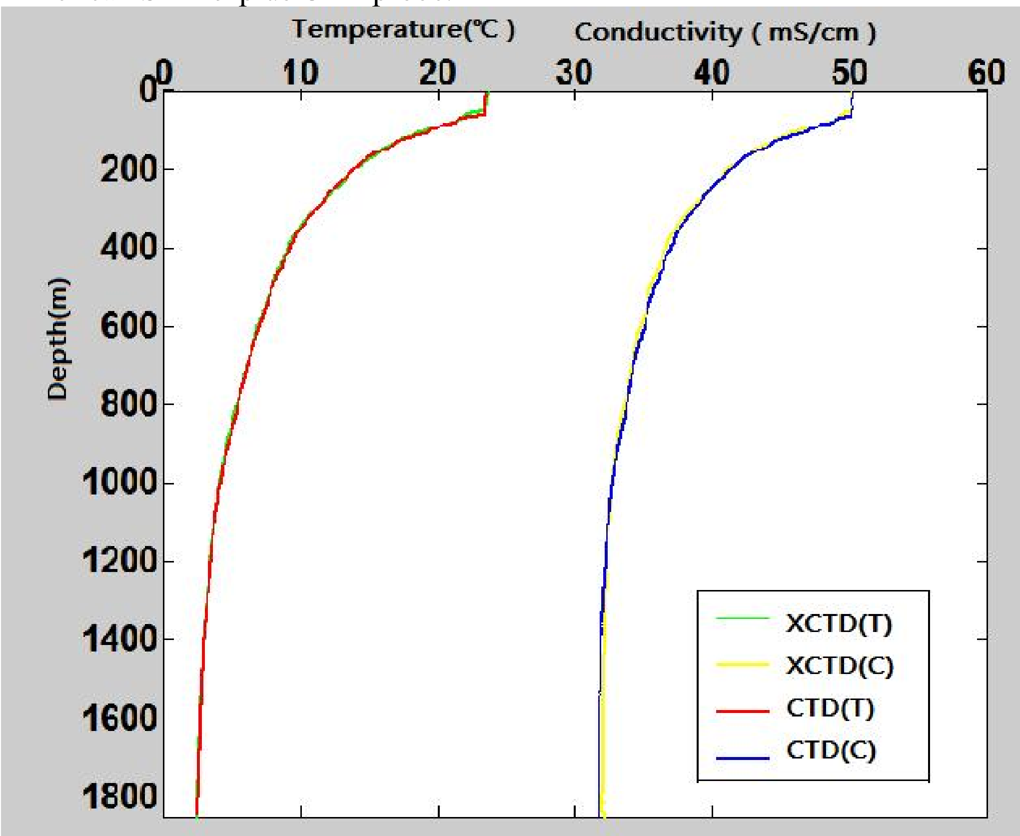

Fig. 3 Measurement curves of XCTD and SEB19 CTD in comparison

Data comparison is conducted as follows:

The temperature and conductivity values measured by SEB19 plus CTD are set to be true values. XCTD and CTD have different sampling frequencies, which leads to different depth data. Therefore, XCTD measurement data need to be interpolated into 1m-interval data files, and then compared with CTD data. Their average absolute errors and correlation coefficients are calculated and shown in Table 3. Seen from the table, the average absolute temperature measurement error of the NOTC-developed XCT-3 XCTD probe is 0.105 ℃～0.159 ℃ and its average absolute conductivity measurement error is 0.093mS/cm～0.197mS/cm. The TSK Company's XCTD-4 XCTD probe has an average absolute temperature measurement error of 0.124℃ and an average absolute conductivity measurement error of 0.119mS/cm. Data comparison demonstrates that domestic XCT-3 XCTD probes and foreign XCTD-4 XCTD probes have no significant difference in measurement error, and their correlation coefficient is above 0.999. The other 7 domestic XCTD probes were launched while the ship was moving at a speed of 4～6 knunder a sea condition of Level 4 or lower, and all of them acquired valid data.

Table 3. Data comparison between XCTD and SEB19 plus CTD

	Temperature		Conductivity	
Probe	Average absolute error (℃)	Correlation coefficient	Average absolute error (mS/cm)	Correlation coefficient
XCT-3 1#	0.159	0.9997	0.156	0.9995
XCT-3 2#	0.105	0.9997	0.093	0.9997
XCT-3 3#	0.118	0.9998	0.114	0.9997
XCT-3 4#	0.145	0.9997	0.197	0.9995

XCT-3 5#	0.122	0.9998	0.182	0.9997
TSK XCTD-4	0.125	0.9996	0.119	0.9997

5. Conclusions

This paper introduces the composition, function, technical performance, and measurement principle of the XCTD profiler developed by NOTC, as well as the key technical problems it has solved, and compares the technical parameters of domestic and foreign XCTD profilers based on laboratory and marine tests, proving that the measurement effect and reliability of domestic XCTD profilers are comparable to those of foreign and American products of the same specifications, and coming to the conclusion that NOTC has developed domestic products with independent intellectual property rights, changed the situation that deep-sea surveys rely too much on foreign equipment, and made major breakthroughs in the equipment and technology for autonomous observation of dynamic marine environment.

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