The latest development of Marine controllable source electromagnetic transmitter

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Abstract. Marine Controlled-Source Electromagnetic (MCSEM) methods have been recognized as an important and effective tool in accurate analysis of shallow electrically resistive structures such as oil, gas and gas hydrate. However, the MCSEM performance in the deep ocean is strongly affected by the hardware design, especially the transmitter system. We have developed a series of deep-towed MCSEM transmitter systems. The design of the transmitter system meets serious challenges such as long-distance and high-voltage transmission, water sealing under high-pressure, the real-time monitoring of seafloor status information 4 km below the sea-surface. In this paper, we present the latest research and development of the MCSEM transmitter systems by presenting key technologies in hardware development and implementation details. The deep tow transmitter system consists of three parts: the deck unit, the deep tow cable and the deep tow unit, which can transmit the high frequency and high power to the seawater, maintaining a high-speed data communication with control center which in the ship's lab. We conducted several experiments in the South China Sea from August of 2010, to November of 2019. The results showed that the development of the transmitter is successful and it can be used for oil, gas and gas hydrate exploration as an effective source.

1. Introduction
The current Marine Controlled-Source Electromagnetic Method (MCSEM) has been recognized as an effective exploration tool for marine oil, gas reservoirs and gas hydrate explorations [1,2,5,6,8,9].

The support of the hardware development is the key to this technology [3,4]. Scripps and EMGS developed a single towed transmitter with multiple static receivers mainly for deep water (deeper than 500 m) [5,12]. Their system is conventional type which employs a continuous signal transmitted by a horizontal electric dipole (HED) source towed about 50 m above the bottom and receivers on the seafloor which measure both horizontal electric filed components and three orthogonal magnetic field components [5]. And of all these systems, the key point is to develop a powerful transmitter.

In 1998, Scripps developed the SUESI-100, SUESI-200 and SUESI-500 transmitters for marine purpose [5]. The transmitter for commercial use was successfully developed by EMGS, PGS and Petromaker [3,12,11,13].

The Chinese geoscientists started research on MCSEM since 2000 mainly by conducting theoretical studies [7,10]. The project of developing MCSEM technology for gas hydrate exploration was granted by China Ministry of Science and Technology from the 11th Five-year period to now when is in the 13th Five-year period. The aim of this paper is to present the latest progress on the development of MCSEM transmitter. We will introduce the the transmitter design while concludes our study with a
marine experiment in order to demonstrate the effectiveness of our transmitter system.

2. Composition of Mcsem Transmitter

![Diagram of MCSEM transmitter system]

Figure 1. Block diagram of the deep tow MCSEM transmitter system.

The block diagram of the deep tow transmitter is shown in Figure 1. The deep tow transmitter system consists of three parts: the deck unit, the deep tow cable and the deep tow unit.

2.1. Deck Unit

In the deck unit, the onboard large power generator outputs 380 VAC in three phases at 50 Hz to provide the electrical energy. The onboard step-up transformer transfers the 380 VAC to the maximum voltage of 2,800 VAC, and the step-down transformer inside the deep tow unit transfers the high voltage to the 20 VAC signal. The onboard monitoring unit includes the onboard computer, the multiplexed optical transceiver, the generator monitoring and the step-up transformer control unit which is used to monitor the status of the onboard large power generator and to control the step-up transformer. All aspects of the deployment and transmission are monitoring real time in the ship’s lab facilitating remote controlling over the MCSEM transmitter and optimization of all acquisition parameters. The information includes transmitter’s posture (pitch, roll and azimuth), position, altimeter and depth of the towed body, vessel (pressure housing) temperature, transmission voltage, current, frequency, the remaining power of the lithium battery of the control unit, and GPS clock comparison information, etc.

According to the requirements of underwater operation, the operator on the ship achieves remote monitoring, sends control commands, and changes the operation modes of the transmitter. The controlling commands include device self-test, change and selection of transmission frequency, selection of transmission waveform and the start or shutdown of transmission.

2.2. Deep Tow Cable

The deep tow cable is a 10,000 m optical-electric combined cable. It includes three electrical cables (the DC resistance of the cable is 4.9 Ω/km) and 3 single mode optical fibers. The deep tow cable is used to transfer the electric power and communication data which enables remote real-time monitoring of important status parameters. The high voltage enables low-loss underwater transmission in the long tow cable.
2.3. Deep Tow Unit

The deep tow unit includes the main body of the transmitter and the neutral floating transmission antenna. The voltage output from the stem-down transformer is rectified to DC voltage which is needed by transmitter inverter module. The DC voltage is inverted to rectangular waveforms by using the main control unit of deep tow transmitter, driving module and transmitter inverter module. We use the driving module inverts the DC power into the multi-frequency rectangular waveform. The waveforms are then transmitted into the seawater through the current electrodes. We use a customized heat dissipation module to transfer the heat to the pressure casing which is dissipated into the seawater. The main control unit of the deep tow transmitter receives the commands and controls the large power inverter through the logic driving module. The unit is powered by Li-Ion battery, and communicates with the deck unit via the communication module and the multiplexed optical transceiver. When any overvoltage, overcurrent or overheating is detected, the driving module will alert the onboard monitoring unit through the main control unit and communication module. We have used two altimeters, one is on the towed body monitoring the distance between the towed body and the seafloor, and another is attached to the far electrode monitoring the distance between the far electrode and the seafloor. The near current electrode is close to the towed body, which means that the distance between the near electrode and the seafloor can also be measured. We can use the output information of the altimeters to adjust the deep tow cable’s length and the ship’s speed to keep the towed body above and avoid touching the sea floor. The current electrodes connected to the neutrally buoyant dipole antenna cable can be positioned accurately via two standard ultra-short baseline (USBL) acoustic transponders. A current signal is generated by the transmitter underwater and send through the cable to the transmitter dipole on the seafloor. The transmitter can follow any given reference signal. All the electronic devices are placed inside the pressure vessels. The transmitter receives monitoring commands from the deck through an optical transceiver and realizes multiple pre-defined functions through the main control unit and auxiliary circuit as shown in Figure 2.

![Figure 2. Functional diagram of main control unit.](image)

3. The Latest Marine Experiment

In November of 2019, we carried out the latest marine experiment using the vessel owned by the Guangzhou Marine Geological Survey. During the experiment, the deep tow transmitter worked for a total of 10 days, and we towed 1 series of receivers and successfully collected the high-quality data. The objective was to investigate the system performance with respect to the future use of detection and characterization of the known deep oil and gas target. The configuration of the MCSEM experiment was conducted in the directions which were shown from Figure 3 to Figure 7.
Figure 3. The experiment site of the transmitter system

Figure 4. The deck unit, step-up transformer and transmitting antennas.

Figure 5. The transmitting antenna and deep-tow transmitter body.

Figure 6. The recorded maximum transmitting current curve (1988A).
Figure 7. The on-board monitoring software unit.

4. Conclusions
Considering the specifics of deep water environment, we have successfully developed a series of marine EM transmitting systems, which incorporate the hydrodynamic condition in the deep ocean, the high-voltage and long-distance power supply, the high-speed bidirectional between the deck and transmitter’s main control circuit, the intelligent transmitter control, the high-power current pulse inverter, and the precise time synchronization between transmitter and receiver. The marine experiments carried out in the South China Sea have proved that the system design and performance is sound and solid. In our future research and development of the marine CSEM system, we will continuously improve the performance and technical index of the system, so that it can be used in the gas hydrate and offshore oil and gas reservoirs exploration.

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