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The deep-tow marine controlled-source electromagnetic transmitter system for gas hydrate exploration☆

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ABSTRACT

The Marine Controlled-Source Electromagnetic (MCSEM) method has been recognized as an important and effective tool to detect electrically resistive structures, such as oil, gas, and gas hydrate. The MCSEM performance is strongly influenced by the transmitter system design. We have developed a deep-tow MCSEM transmitter system. In this paper, some new technical details will be present. A 10,000 m optical–electrical composite cable is used to support high power transmission and fast data transfer; a new clock unit is designed to keep the synchronization between transmitter and receivers, and mark the time stamp into the transmission current full waveform; a data link is established to monitor the real-time altitude of the tail unit; an online insulation measuring instrument is adopted to monitor current leakage from high voltage transformer; a neutrally buoyant dipole antenna of copper cable and flexible electrodes are created to transmit the large power current into seawater; a new design method for the transmitter, which is called "real-time control technology of hardware parallelism", is described to achieve inverting and recording high-power current waveform, controlling functions, and collecting auxiliary information. We use a gas hydrate exploration test to verify the performance of the transmitter system, focusing on more technical details, rather than applications. The test shows that the transmitter can be used for gas hydrate exploration as an effective source.

1. Introduction

The Marine Controlled-Source Electromagnetic Method (MCSEM) has been recognized as an important and effective exploration tool for electrically resistive structures, such as oil (Constable, 2006b; Constable and Srnka, 2007), gas (Myer et al., 2012), gas hydrate (Schwalenberg et al., 2005; Weitemeyer et al., 2006), and geological structures(Cox et al., 1986; MacGregor et al., 2001). With many successful applications being reported, much attention has been paid to the research and development of this technology (Edwards, 2005; Smit et al., 2006; Hesthammer et al., 2010; Constable, 2010).

The hardware development support is key to this technology. SIO (Scripps Institution of Oceanography) (Constable, 2006a, 2010, 2013), EMGS (Eidesmo et al., 2002), and University of Cambridge (Sinha et al., 1990) have developed towed transmitters with multiple static receivers mainly for deep water (deeper than 500 m) application. SIO has a long history of development of the MCSEM transmitters (Cox et al., 1986; Webb et al., 1993; Constable, 2006a, 2013). SIO also developed the VULCAN system which is a deep-towed CSEM receiver (Constable et al., 2012, 2016), PGS developed a cable-towing EM system with a single surface-towed transmitter and multiple synchronically towed receivers mainly for shallow water (McKay et al., 2015). A ship-towed, electric dipole-dipole transient electromagnetic system with a single transmitter and several towed receivers has been developed by the University of Toronto (Edwards, 1997; Yuan and Edwards, 2000). In all these systems, the key point is to develop a powerful and effective transmitter.

SIO has developed the SUESI-100, SUESI-200, and SUESI-500 transmitters (Constable, 2010, 2013). The transmitter for commercial use was successfully developed by PGS (McKay et al., 2015) and EMGS. EMGS had provided the support for Shell in the acquisition described by Darnet et al. (2007).

In China, a project which was funded by China Ministry of Science and Technology from 2006, started developing MCSEM technology for gas hydrate exploration (Deng et al., 2010). The aim of this paper is to provide more technical details of the transmitter than Wang et al. (2015b).

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Table 1
Comparison of the deep-tow MCSEM transmitters of SIO[a] and CUGB[b]. SIO uses its transmitter to research marine geoscience structures and submarine hydrocarbon. CUGB uses its transmitter system to explore gas hydrate.

	SIO	CUGB
Maximum transmission current	500 A	250 A[c]
Transmission dipole length	Up to 300 m	150 m
Transmission dipole moment	150 kA·m	37.5 kA·m
Transmission frequency	0.01–10 Hz	0.01–10 Hz
Transmission waveform	SQS, ORS	SQS, ORS, and PRBS[d]
Positioning method	USBL[e]	USBL
Depth rating	6000 m	4000 m
Deep-tow cable used for high-power and data transfer	Coaxial tow cable	Optical-electrical composite cable
Speed of data transfer	9600 bit/s, multiplexed on single port	115,200 bit/s, multiple ports
Length of the deep-tow cable	Up to 10,000 m	10,000 m
The maximum transmission power by deep-tow cable	30 KVA	72 KVA
The stability of transmission frequency	Stable	10^{-8} s/s[f]
The way to monitor the altitude of the tail unit	USBL + Depth gauge (telemetry depth)	USBL + Altimeters
Real-time current monitoring and recording	Yes	Yes

[a] SIO - Scripps Institution of Oceanography.
[b] CUGB - China University of Geosciences (Beijing).
[c] The maximum transmitting current is 250 A, and we use 150 A in the experiment.
[d] SQS - Standard Square-wave. ORS -Optimized repeated sequence. PRBS –Pseudo-Random Binary Sequences. ORS and PRBSs contain multiple frequency harmonics.
[e] USBL is a method of underwater acoustic positioning.
[f] ‘s/s’ refers the time offsets per second and is used to indicate the stability of transmission frequency.

2. General description of the MCSEM deep-tow transmitter system

The diagram of the MCSEM deep-tow transmitter system is shown in Fig. 1. The deep-tow transmitter system consists of three parts: the deck unit, the deep-tow cable, and the deep-tow unit. We have added considerable detail based on the original figure of Wang et al. (2015b). We use the whole system to establish the controlled source electromagnetic field in seawater. While, at the same time, monitoring most of the real-time status information of the system through high-speed data communication. AHRS (Attitude Heading Reference System) is connected to one channel of the multiplexed optical transceiver. The onboard computer receives the data from the AHRS at 1 Hz rate. We have used two pressure cases to contain the electrical devices in the towed body. One (“transmission case”) contains the transmission inverter module, driving module, heat dissipation module, and current sensor. The other devices shown in the figure of the towed body (except the altimeter USBL (Ultra-Short Baseline) acoustic transponder, CTD (Conductivity, Temperature, and Depth) sensor, step-down transformer and rectifier) are contained in another one (“control pressure case”). We use several water proof cables to connect the two pressure cases.

2.1. Main control unit of transmitter

The transmitter completes control functional with various response times. If the transmitter only has one control unit controlled by centralized software, there is the danger that it may not work steadily for a long

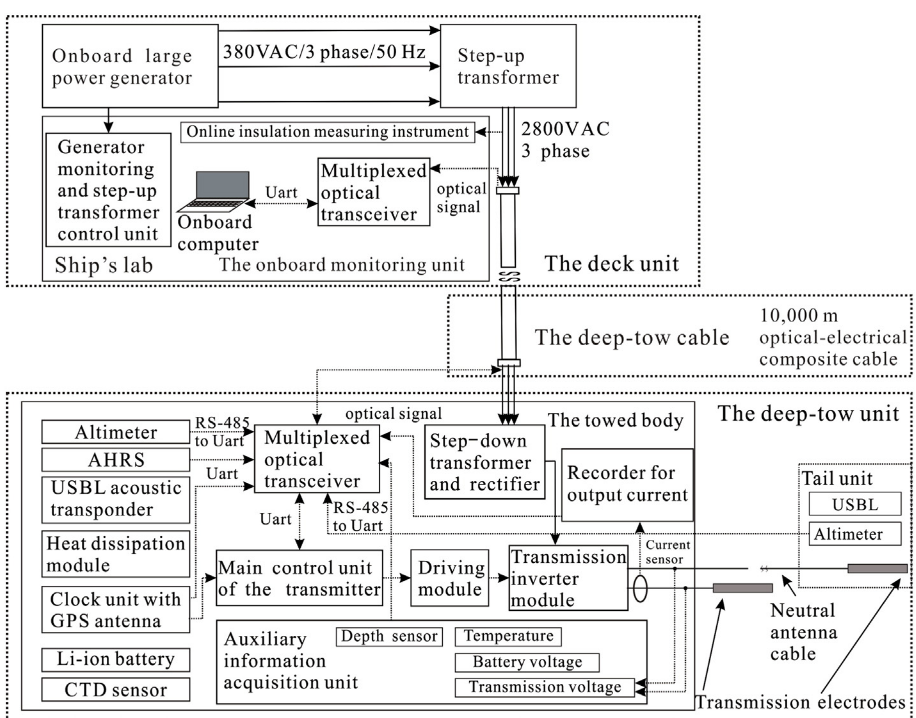

Fig. 1. Diagram of the deep-tow MCSEM transmitter system. We have added the AHRS, tail unit, recorder for output current and voltage, clock unit with GPS antenna, online insulation measuring instrument, and concrete auxiliary information acquisition. The solid line shows the high power signal, the dashed line represents the low-power signal.