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Deep-towed High Resolution multichannel seismic imaging

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ABSTRACT

High Resolution (220–1050 Hz) seismic acquisition performed in deep water using deep-towed systems provides unrivalled lateral resolution when compared to conventional surface seismic. The lateral resolution of these acquisitions is controlled by the width of the first Fresnel zone, taking advantage of their positions close to the sea bottom. No current existing deep towed equipment can benefit from seismic imaging processing techniques to improve this resolution as a consequence of positioning inaccuracies. The technological developments of a digital deep-towed multichannel streamer are presented with a particular attention to positioning: each hydrophone incorporates a pitch, roll and heading sensor in order to monitor the constant deformation of the streamer in operation. The sea trials took place in July 2013 in the Mediterranean Sea. Pre-stack depth migration applied to the deep-towed multichannel data illustrates the potential of this emerging methodology in terms of penetration (12 dB improvement in Signal/Noise) and lateral resolution (mean signal wavelength: 3 m) when compared with deep-towed single-channel acquisition.

1. Introduction

High Resolution (220–1050 Hz) seismic acquisition performed in great water depth using deep-towed systems arouses interest, because of its ability to provide detailed information on the subsurface. Fields of interest include seabed instability, gas and gas-hydrate studies, and high-resolution seismic stratigraphy. The relatively low frequency content of such a system and the high Sound Level, compared to standard AUV-borne sub-bottom profilers, enable it to provide deeper penetration (hundreds of metres) and to explore rougher terrains where higher frequencies are ineffective. The keystone of this emerging technology is the Janus-Helmholtz piezoelectric transducer, a mature development designed for wide-band frequency modulated signals, which provides a hydrostatic pressure-independent seismic source down to 6000 m water depth (Ker et al., 2010; Leon et al., 2009; Marsset et al., 2010; Riboulot et al., 2013; Rowe and Gettrust, 1993; Sultan et al., 2010, 2011).

The US Naval Research Laboratory (NRL) has pioneered the use of deep-towed high-resolution multichannel seismic acquisition. The NRL Deep Towed Acoustic/Geophysical System (DTAGS) has successfully determined P-wave velocity distribution and thus acoustically characterized the medium (Chapman et al., 2002; Gettrust et al., 2004; He et al., 2002; Walia and Hannay, 1999; Wood et al., 2003, 2008). Yet, due to inadequate spatial sampling (20 m hydrophone interval, 20 m shot interval), the DTAGS could not benefit fully from the multichannel receivers for seismic imaging. Moreover, the DTAGS streamer lacks positioning accuracy to meet high-resolution seismic imaging requirements (Asakawa et al., 2009).

Taking advantage of its existing SYSIF (Deep Towed Seismic System, Leon et al., 2009) technology in deep-towed seismic source and single-channel data acquisition, IFREMER (French research institute for exploitation of the sea) has recently developed a deep-towed multichannel streamer. This contribution presents the technological challenges of deep-towed seismic imaging issues, the technological developments needed to meet these challenges and the first seismic imaging results of this emerging methodology.

2. Imaging requirements

To benefit from seismic imaging, an adequate spatial sampling is required to avoid spatial aliasing. Given the high frequency

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content of the Janus-Helmholtz seismic source (220–1050 Hz), a trade-off has to be found between the maximum dip that can be imaged and practical technological considerations. The prototype streamer was developed with a 2 m inter-trace spacing (Dx), which prevents spatial aliasing for dips (Θ) up to 10° for frequencies lower than 500 Hz ($Dx < velocity/(2 \times frequency \times \cos(\Theta))$).

Velocity analysis as well as the imaging process rely on the source–receiver offset range, thus on the number of seismic channels and on the streamer length. The prototype streamer was developed with 52 seismic channels (offset: 10–112 m) which enables velocity analysis within the upper sedimentary layers (Normal Move Out of 20 ms at sea floor for an altitude of 100 m for the maximum offset). The streamer length therefore complies with the up-to 40° from-vertical directivity of the Janus-Helmholtz transducer for a minimum towing altitude of 50 m.

Operating in deep water depth (over 500 m), positioning accuracy becomes an issue, not only for relative positioning, i.e. source to receiver geometry but also for absolute positioning, i.e. geographical positioning. Considering the high-resolution imaging objective, optimal positioning accuracy should therefore reach: (1) a horizontal precision better than the mean signal wavelength (<3 m) and (2) a vertical precision in the order of the associated sampling rate (0.1 ms or 0.2 m).

3. Technological developments

The hydrophones should withstand high hydrostatic pressure without loss of sensitivity. The actual hydrophones consist of piezoelectric ceramic cylinders with end caps. This technology is capable to withstanding pressure to 700 bars and was used in most places in the design of deep towed streamers (Breitzke and Bialas, 2003; Leon et al., 2009; Rowe and Gettrust, 1993; Wood et al., 2008).

Given the exceptionally low noise level of the environment in deep-towed acquisition, each seismic trace is acquired with a single hydrophone unlike the conventional surface towed seismic trace which requires an arrangement of hydrophones to filter out hydrodynamic noise. Because the number of hydrophones would imply a too large number of electrical wires, it is not possible to use analogue technology; therefore digital hydrophones were designed taking advantage of the Ethernet transfer protocol. Ethernet switches are included throughout the streamer to reduce the number of electrical wires.

The development of digital hydrophones (Fig. 1) took advantage of the inner cavity, at atmospheric pressure, of the cylindrical stack of ceramics to house the electronic board. The multi-layer technology was used to optimize the size of the board, the dimensions of which are 18 mm × 70 mm. The kernel of the electronic board is a 32-bit microcontroller allowing local numerical data processing. The microcontroller includes an Ethernet bootloader allowing potential reprogramming of the board while integrated in the streamer. The function of the hydrophone electronic board is four-fold: (1) analogue signal conditioning (band-pass filtering: 150–3000 Hz and pre-amplification: 26 dB), (2) analogue to digital conversion (24 bits, 10 kHz), (3) ethernet communication and (4) providing pitch, roll and heading from a microelectromechanical system (MEMS) sensor. Each electronic board, on reception of a trigger signal delivered by the seismic source, collects 1 s of acoustic signal and sends it over the ethernet network. The MEMS data are embedded in the ethernet data flow. The hydrophones are HTI90 (sensitivity without pre-amplifier: −186 dB ref 1 V/μPa) from HighTech Inc., the electronic board, developed by Ifremer, was embedded by the hydrophone manufacturer.

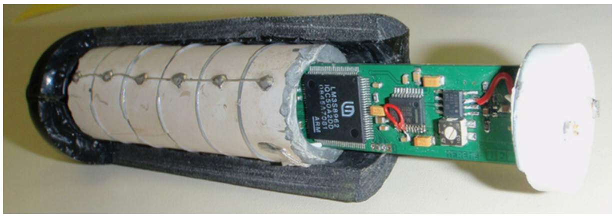

Fig. 1. Exploded view of the digital hydrophone, the coating was removed to expose the electronic board in the stack of ceramics.

The Ethernet switches were designed to collect single hydrophone data in order to merge the Ethernet flow. Each switch handles 8 Ethernet ports (7 in, 1 out), the electronic board being housed in a titanium cylinder (46 mm diameter, 266 mm long excluding connectors). The purpose of the electronic switch board is three-fold: (1) Ethernet communication, (2) power conditioning, and (3) trigger conditioning.

The prototype streamer is made of 4 independent acoustic sections of 13 hydrophones and 2 Ethernet switches each, the individual electrical scheme of these sections includes 8 wires (i.e. 32 wires for the whole streamer): 2 wires for power, 2 wires for trigger and 4 wires for the Ethernet connection.

The hydrophones and the switches were incorporated in a conventional oil-filled streamer. The outer diameter of the streamer is 55 mm and the skin is 2 mm thick. The streamer weights 500 kg in air, it is balanced (Isopar M) to be neutrally buoyant for a temperature of 2 °C and a salinity of 33 g/l. The buoyancy can be adjusted by adding lead strips to meet the local environmental values. Because of the length of the titanium containers, which limit the radius of curvature to 1 m, a dedicated hydraulic winch was developed to host the streamer (Fig. 2).

The streamer is connected to the SYSIF towed fish, hosting the seismic source, through a 32 pins pressure-resistant connector. The armoured electro-optical cable delivers the power to the towed fish and receives the Ethernet data flow (≅10 Mbits/acquisition). A bi-directional Focal optical telemetry transmits the Ethernet seismic data, the navigation data and the different controls to the surface. The trigger signal is sent by the SYSIF seismic source through the cable to trigger a Meinberg GPS clock, to precisely date the seismic data.

The navigation of the seismic source is achieved through an acoustic 120 kHz Simrad altimeter, a Paroscientific pressure sensor and a miniature Xsens attitude and reference system. The positioning is ensured by the Acoustic Ultra Short Base Line (USBL) iXblue Posit 14–16 kHz. The depth/altitude (height above sea bottom)/attitude data are acquired at sampling rates of 10 kHz and sent to the surface, through the optical telemetry, where they are recorded for processing purposes. The streamer behaviour is

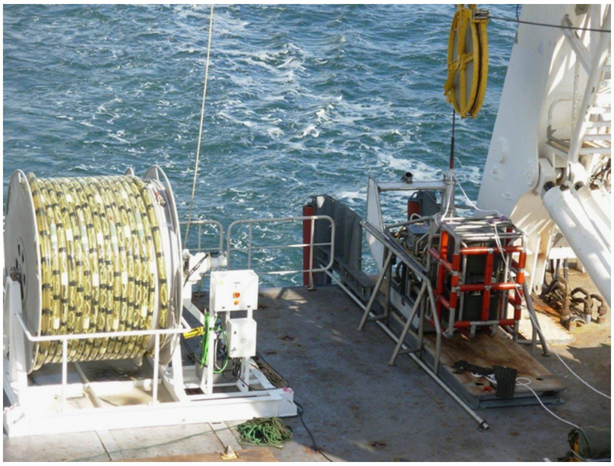

Fig. 2. The seismic streamer on its winch (left), together with the SYSIF towed fish hosting the seismic source (right).