True Vertical and Orthogonal OBN Sensing with 3C MEMS Sensors

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Summary

OBN projects are taking an increasing market share over towed streamer surveys. Despite significantly higher costs of operation, OBN enable flexible layout strategies (e.g., for the recording of long multi-azimuth offsets), seismic wavefield recording with high signal-to-noise ratio (stationary sensors located in a low-noise environment), broadband signal recording (exceptional deghosting with receiver ghost well separated from the primary signal, in combination with dual pressure and velocity sensing), the recording of PS waves and a better repeatability for 4D surveys. Until now all OBN available on the seismic market have been equipped with 3C omni-tilt 15Hz geophones however a recently released node offers 3C MEMS sensors as an alternative. MEMS are renowned for their ability to record seismic signal with true amplitudes and phases, from DC to 800 Hz, contrary to geophones whose sensing fidelity varies with manufacturing tolerances, ageing and temperature. In addition, the third generation of MEMS (Lainé 2014, Fougerat 2018) has overcome the low-frequency limitations associated with previous generations. A recent field test could demonstrate that contrary to the case with 3C geophones, 3C MEMS have in addition the ability to measure particle motion along truly vertical and horizontal axes, which is a major benefit for OBN applications.

Introduction

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Why do MEMS preserve verticality in OBN?

Good MEMS accelerometers are fitted with a feedback loop that enables the measurement of static signals (DC/0 Hz), such as the Earth gravity. Thanks to this feature and contrary to the case with 3C geophones, 3C MEMS sensors can be easily factory-calibrated by using a very accurate gravitational acceleration reference: the manufacturing orthogonality tolerances of the three axes can consequently be compensated for. Similarly, the particle motions measured can be projected along an exact vertical axis and two perfectly horizontal axes for the entire duration of the recording time, from node deployment to node recovery. As a result, 3C MEMS sensors with DC capability have an excellent vector fidelity, which combined with their true amplitudes and timing capability, enable thorough separation of the polarization of the different wave types and rigorous analysis of anisotropy. The high-fidelity data recorded in this way avoids the need for data-driven sensor rotation solutions with projections onto the vertical that have numerous limitations related to processing software, operators' practices, water depth, offset and azimuthal coverage, data SNR and bandwidth, as well as on the level of contamination between interfering blended sources.

From an operational perspective, the 3C MEMS channel is also omni-tilt and compact. The MEMS tiny size allows for a correspondingly small housing form-factor, thus enabling an efficient rejection of parasitic signals, such as surface waves induced rotations.

Field tests

It is worth noting that MEMS sensors already enjoy a proven track record of success in ocean-bottom cable systems (e.g., SeaRay system, see Archer 2012 and Keggin 2017). The first OBN system equipped with 3C MEMS sensors has been introduced very recently and a comparative field test carried out. Two lines of 28 ocean-bottom nodes were deployed at shallow depth (20-30 m). At each receiver station (spaced 100 m), two nodes were collocated, one equipped with standard 15 Hz 3C geophones, the other with low-noise 3C MEMS. A 10 km source line was shot with a 25 m source interval.

The analysis of this test campaign is still ongoing at the time of redacting this abstract, however, the verticality accuracy of the MEMS data is already clearly superior to that of the geophone data. The processing applied for the sensor CRGs presented in figure 1 was limited to sensor de-signature from mV to $m.s^{-1}$ (for geophones: phase and amplitude compensation for natural frequency, damping and sensitivity; for MEMS: integration from acceleration to velocity and sensitivity compensation). The vertical component (Z) was reconstructed by using the tilt sensor measurement for geophones, and the built-in sensor tilt determination for MEMS. Figure 1 displays a sample of a Z CRG after the application of a 16-31 Hz bandpass filter. In the difference section, the disappearance of the vertically polarized P waves illustrates the performance of the deterministic sensor designature, while the remaining strong shear wave energy with a ‘near’ horizontal polarization, and so with the highest sensibility to non-verticality, illustrates a tilt difference between the Z-MEMS and the Z-Geophone.

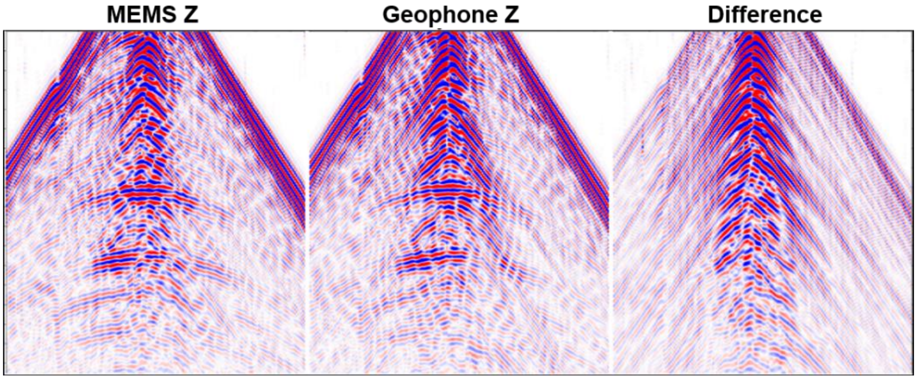

Figure 1: Example of CRG in m/s, 16-31 Hz bandpass filter, time window 0.5-2.2 s.

A detailed study of the direct water layer arrival (CRG sample in figure 2, with LMO 1490 m/s) definitively proves the exact verticality of the MEMS and an erroneous one for the geophones. As a matter of fact, at long offsets and with small source – water bottom vertical distance of 20 m, the direct P wave should be polarized quasi horizontally, so with negligible Z component. As expected, on the MEMS Z data, only interfering patterns of refracted waves are observable. This verticality error, observed on all 28 geophone CRGs, indicates that it is not related to an isolated failure of a tilt sensor on a given geophone node; it cannot in addition be corrected by processing means, due to strong interference between the different wave types in a shallow water context. This interference would also predominate in records acquired with blended acquisition, now a standard acquisition technique in OBN. This non-verticality of geophones could also be observed through the presence of high-frequency diffractions at unexpected times (t > 3 s, not displayed).

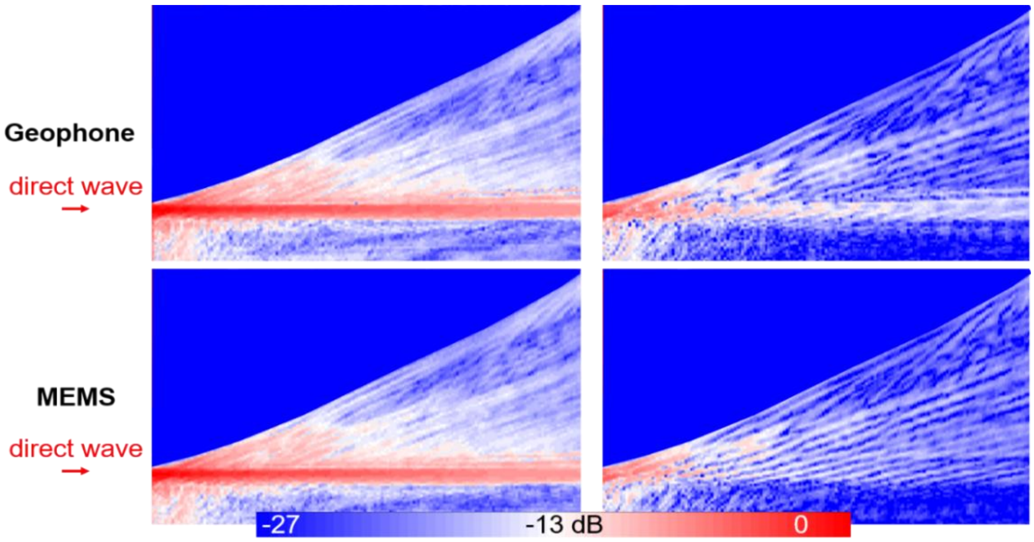

Figure 2: Signal envelopes in dB (m/s)for the geophone data (top) and MEMS data (bottom). (X,Y,Z) envelope (left), and (Z) envelope (right).

Conclusions

Unlike 3C geophones, 3C MEMS sensors enable direct access to built-in true verticality and to excellent vector fidelity. Along with their ability to record true amplitudes and phase on the entire seismic bandwidth of interest, MEMS thus appear as a good alternative to geophones to provide the industry with high-fidelity datasets, and accompany the processing of the highly blended datasets usually associated with OBN operations. The analysis of the datasets acquired is at the time of writing continuing, further results will be presented and discussed.

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