A paradigm shift in marine seismic: broadband full offset full azimuth 4C acquisition with Midwater Stationary Cable

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Summary

The limitations of the conventional streamer acquisition technique are first presented and then the new offshore acquisition method named Midwater Stationary Cable is explained. By employing unmanned autonomous vessels to control independent cables the method brings key advantages: extreme flexibility, full offset full azimuth, low acquisition noise, and 4C recording. The usual noise sources such as flow noise, mechanical noise and swell noise are possibly completely suppressed. The advantages are precisely quantized using bibliographic references and physical considerations. Test results are finally presented to confirm the theoretical derivations.

Introduction

Legacy offshore seismic acquisition techniques are currently reaching limitations and the long lasting economic downturn put them in difficulty. Oil companies are indeed looking for faster, better and cheaper solutions. The first historical technique, the towed streamer, is going for always more gigantism and capital intensive vessels. The paper describes how the new MSC acquisition method differs from the streamer, explains its technical advantages and precisely quantizes them based on theory confirmed by experimental measurements.

Streamer technique limitations

The main benefit of the towed streamer is its productivity since both the source and the receiver cables move at a speed of 5 knots. The productivity is directly proportional to the spread width which depends on the number of towed streamers. This is the first limitation that the technology currently faces: despite the introduction of bigger and bigger vessels, the total number of cables is reaching a limit due the hydrodynamic forces needed to make the spread diverge.

A second limitation of the streamer is the acquisition noise:

- The flow noise created by the water flow around the cable, as described in Elboth *et al*. (2010).
- The mechanical noise due to tension, quantized e.g. in Schoenberger *et al*. (1974).
- The swell noise due to wave motion and wind effects, explained in Elboth *et al*. (2009).

Finally the third and major limitation of the towed streamer is its acquisition geometry. Since the relative positions between source and receivers are constant, the azimuth and offset distributions are limited. Variants were introduced to overcome this limitation: the MAZ repeats the number of sailing passes, and the RAZ uses more source vessels and/or seismic vessels. The combination of both techniques possibly leads to rich azimuth (RAZ) as in e.g. Long (2009) and Baldock *et al.* (2011). The coil shooting or shooting-over-the-spread are recent examples. The main drawback is that operational costs are largely increased. Moreover the acquisition does not lead to full offset full azimuth homogeneous distribution in an isotropic bin. WAZ and MAZ rose plots are displayed on Figure 1.

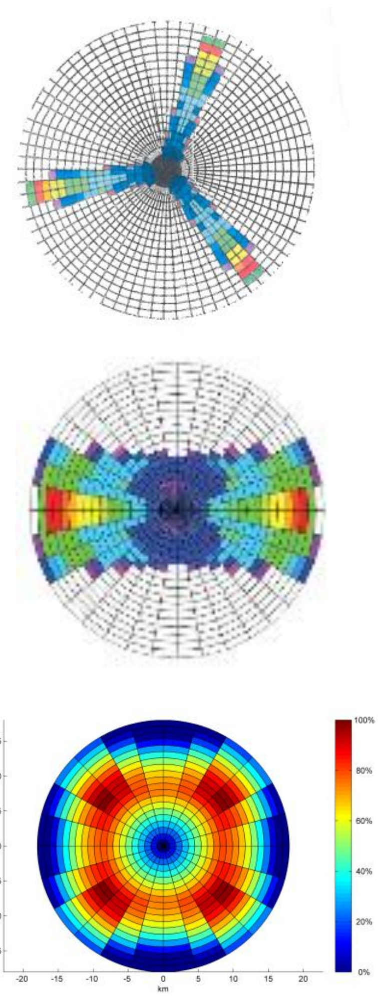

Figure 1: from top to bottom: rose diagram obtained with MAZ, WAZ and MSC acquisitions

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MSC acquisition principle

The MSC (Midwater Stationary Cable) acquisition technique was recently introduced in Haumonté *et al.* (2016a). Its basic principle consists in using an array of physically independent seismic cables, which are autonomously controlled by unmanned surface vessels named RAV (Recording Autonomous Vessel). The cables are placed in plain water at relatively large depth - typically 100m - and their depth is precisely controlled. Having independent cables and a self-controlled system allows multiplying the number of cables: the receiver spread is largely increased and the system can move slowly and still sustains good productivity. This allows independent shooting vessel(s) to shoot perpendicular to the cables.

MSC advantages

First of all the MSC acquisition geometry is extremely flexible. The separation between the cables, the length of the cables, the cable depths, the shooting pattern, and the array progression speed are all degrees of freedom. The survey design can be tuned to match the survey requirements and to image the geological target in the most efficient manner. The system itself is easy to mobilize and extremely flexible to operate: it can address very different offshore environments (shallow water, deep water, landlocked seas, and obstructed areas with presence of obstacles or traffic). Complex situations can be circumvented by exploiting the maneuverability of the system, its light impact and low footprint.

The main geophysical advantage is that the MSC method produces a full azimuth and full offset distribution (Figure 1). Indeed the 2D space is ideally sampled in both directions: inline sampling from the receiver spacing (25m) and crossline sampling from perpendicular shooting (25m shot point interval). The natural bin is isotropic and perfectly square (12.5m x 12.5m) and the CMP coverage is high, e.g. 400-fold with twenty 8-km long cables, leading to a 26dB post-stack SNR improvement.

Another key advantage of the method is the acquisition quality obtained through low measurement noise and good acquired signal. The noise level is weak thanks to three main reasons.

1. Since the spread is moving slowly, the water velocity w.r.t. cable is small and limited to the sea current. At 100 m of depth the current is generally much weaker than at surface. A 0.5 knot leads to a 40 dB flow noise reduction over streamer case (5 knots) using square law assumption as in Schoenberger *et al.* (1974).

2. It can be derived that the swell impact exponentially decreases with depth z:

- Water particles at depth z follow a circle of radius r:

$r = r_0 \cdot \exp(-2\pi \cdot z/\lambda)$

- Water particle velocity is equal to:

$u = 2\pi \cdot r_0 \cdot V/\lambda \cdot \exp(-2\pi \cdot z/\lambda) \cdot \sin(2\pi\,(t/T - x/\lambda))$

- Water pressure is obtained through:

$p = 2\pi \cdot r_0 \cdot \rho/T \cdot \exp(-2\pi \cdot z/\lambda) \cdot \sin(2\pi\,(t/T - x/\lambda)) + g \cdot z + cte$

where r_0 is half the swell height, V is the swell propagation speed, λ is the swell wavelength, and T is the swell period. V, T and λ are linked through $V = \sqrt{(g \cdot \lambda/2\pi)}$ and $\lambda = V \cdot T$.

The sinewaves imply low frequency and slowly moving disturbances. The terms in front of the exponential are the amplitudes u_0 and p_0 at sea surface. A numerical application with r_0=2.5m and T=9.8s (150-m wavelength) yields u_0 = 1.60 m/s and p_0 = 0.24 bars. Hence streamer are highly impacted by swell motion. Firstly they are mechanically disturbed and brewed by swell agitated water layer (r = 1.8m at 7.5m). Secondly the acoustic noise is strong at typical towing depth. The exponential decay is only 73% at 7.5m (classical streamer), 35% at 25m (dual streamer) and 12% at 50m (slanted streamer). At MSC operating depth (100m) the decay is 1.5% corresponding to a swell noise reduction of respectively 33dB, 27dB or 18dB w.r.t. classical, dual-sensor and slanted streamer.

3. The mechanical tensions in the MSC are weaker than in the streamer because the MSC does not fight against crossflow and the inline tension varies with the square of the water speed. Indeed the hydrodynamic force along a cable of length L_c and diameter D_c moving inline at speed v can be computed as $F = 0.5 \cdot \rho \cdot v^2 \cdot (\varepsilon_f \cdot L_c \cdot \pi \cdot D_c + c_d \cdot S_c)$, where the first term corresponds to the inline friction force (ε_f is the friction coefficient) and the second term corresponds to the transverse pressure force (c_d is the transverse pressure drag coefficient and S_c the transverse projected area). Streamers have to use paravanes to make the spread as large as possible and the cables move at 5 knots. The tension at the paravane reaches 60-80 tons and the tension along the streamer is several tons, while the tension in the MSC is in the order of a few hundred kgf. Consequently the level of vibrations, the tug noise and the strumming noise are largely reduced in the MSC case. Schoenberger *et al.* (1974) has shown a strong dependency with tension and the results suggest a dependency of the towing noise and of the cable vibration with the square of the towing speed. For MSC the mechanical noise reduction corresponds to 40 dB for a 0.5-knot current.

The low acquisition noise leads to high SNR. The MSC technology is able to acquire good signals on all four components at low frequency as shown in Haumonté *et al* (2016b). Particularly geophones have good low frequency content. As a consequence, the receiver deghosting can be done at any depth through PZ summation with raw data - while it is typically limited to 30m with dual sensor technology because of noise. The deghosting with MSC has been verified through tests at 7, 15, 30, 50, 100 and 120m of depth. Placing the cable deep, not only put the receivers at a quiet location, but also places the first notch at low frequency (7.5 Hz at 100m) and increases the slope of the hydrophone response.

The fact that all four components record useful signal opens interesting possibilities. In the presence of complex seabed and subsurface, the seismic energy may come from any direction. In some survey MSC did measure strong signals even on its inline components. Moreover having 3C velocity measurement permits vector fidelity check, polarization filtering, vector processing and 3D angle processing.

Experimental results

Experimental results are extracted from different test campaigns that were carried out with the MSC to validate and gradually improve the technology. The first results come from a test done at Seneca Lake. This extremely quite environment is such that measurements are not disturbed by flow noise and mechanical noise. Figure 2 compares the signal recorded from a single and small airgun (3 cu in) at 30m and 120m of depth. The spectrum exhibits signature modulations. It is clearly visible that the noise level below 20Hz is much higher at 30m than at 120m as predicted by the theory.

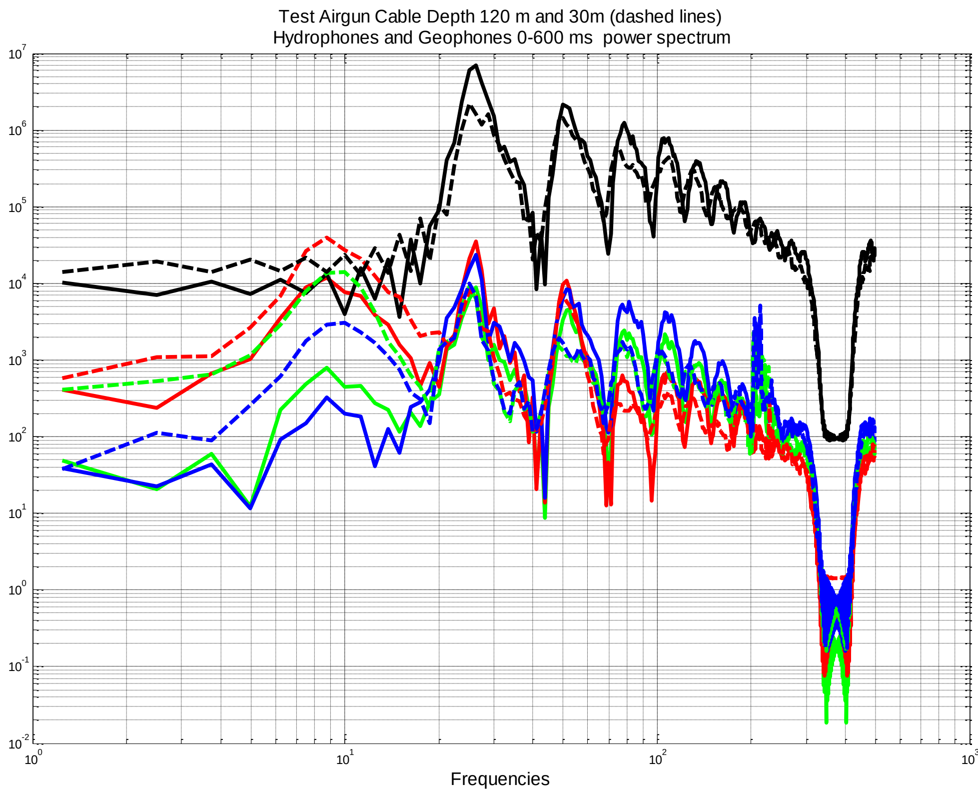

Figure 2: single airgun 4C spectrum at 30m (dashed line) and 120m (solid line): hydrophone (black), in-line geophone (red) and crossline geophones (green and blue) - unmatched absolute scale

The second results come from a test done in the Mediterranean Sea with a 1-km MSC at 30m of depth during which the speed was gradually increase from 1 knot to 3 knots. The rms maps are displayed on Figure 3: hydrophone and geophone plots coherently exhibit an increasing noise level with speed. The rms values from unfiltered raw data (DC to 250 Hz) are displayed vs. speed on Figure 4. The 2nd order polynomial fit accurately interpolates the measured points for both hydrophone and geophone measurements. Note that since the tension also varies with speed, flow noise and mechanical noise are characterized simultaneously: the sum varies with the speed squared which is line with above section.

Conclusion

In this paper the conventional streamer technique was discussed along with its limitations. The MSC was presented and its key advantages were described: acquisition flexibility, full offset full azimuth, high quality thanks to low acquisition noise (flow noise, mechanical noise and swell noise significantly reduced) and good signal on all four components. Theoretical derivations were confirmed with experimental data. The MSC technology seems well suited to address high end seismic offshore exploration such as imaging deep complex geological structures, for instance below salt targets.

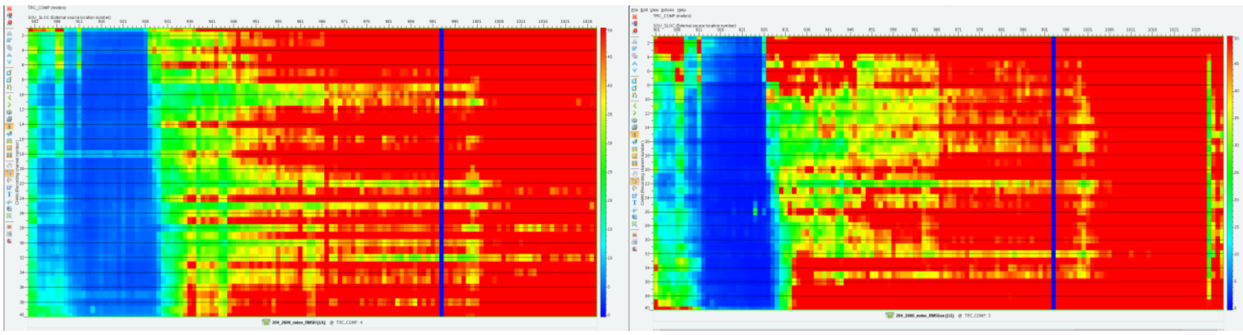

Figure 3: hydrophone (left) and crossline geophone (right) noise maps in tow test (from 1 to 3 knots)

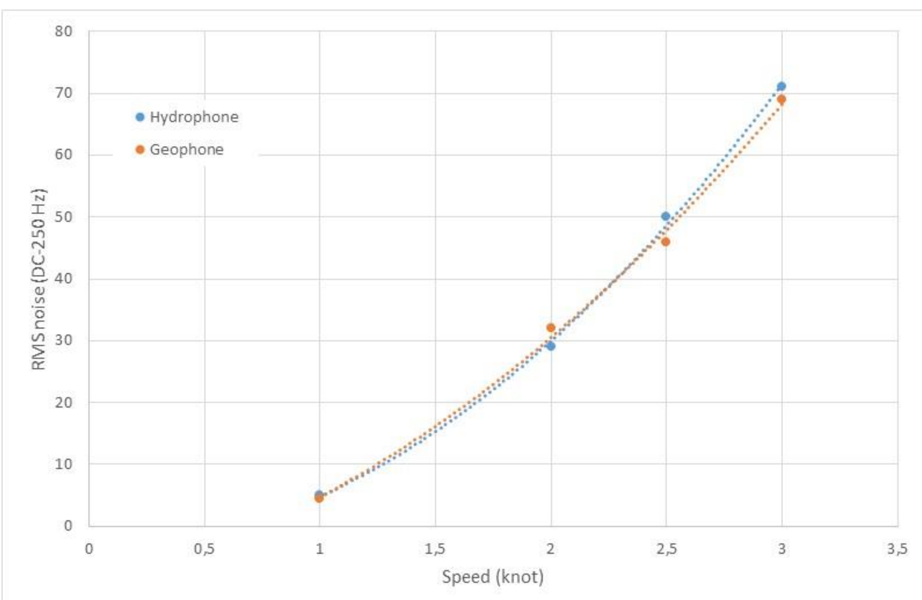

Figure 4: rms noise values from raw data (unfiltered DC-250Hz) vs. speed during towing test

EDITED REFERENCES

Note: This reference list is a copyedited version of the reference list submitted by the author. Reference lists for the 2017 SEG Technical Program Expanded Abstracts have been copyedited so that references provided with the online metadata for each paper will achieve a high degree of linking to cited sources that appear on the Web.

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