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Considerations About Multi-Sensor Solid Streamer Design

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Summary

Multi-component recording of seismic data with two components and four components has been in use in shallow water environments for nearly three decades. The use of motion sensors for streamer marine acquisition has a much shorter history. The earliest system introduced by PGS in 2007 used a combination of hydrophones and gimbaled vertical geophones, but in recent years two additional systems have been deployed that also record the horizontal motion of the streamers in the crossline direction. The motivation for the introduction of the vertical sensor was to improve the spectral content of the data, while for the horizontal sensor it is to enable sensor rotation when gimbals are not being utilized. This paper describes the design considerations and characteristics of one of these systems, and compares seismic data acquired on a recent production survey and produced with either hydrophone-only or joint deghosting.

Introduction

The water-to-air interface at the surface of the ocean has a very large acoustic impedance contrast that results in an almost perfect reflection of any upgoing energy arriving at the surface. Since the reflection coefficient is approximately equal to -1, the polarity of the resulting downgoing pressure wave is reversed. This downgoing energy is typically referred to as the “ghost” and results in both constructive and destructive interference of the upgoing and downgoing wavefields. The frequencies over which these effects are observed depend on the sensor type, the sensor depth below the water surface and water velocity. The attenuated frequency ranges are commonly termed “ghost notches” and can severely limit the interpretability of the data. Ghost effects occur at both the source and the receivers.

In 1956, Haggerty (US Patent 2,757,356) patented the use of both pressure and motion sensors to attenuate the effect of the ghosts for the receivers. He also patented the use of deploying sensors at different depths to enable the separation of the upgoing and downgoing wavefields. Unfortunately, marine towed streamers exhibit significant vibration modes (Tenghamn et al, 2009) that create noise on any motion sensors that are deployed within the streamer. In the early days of data acquisition with streamers, these vibrations affected both pressure and motion sensors until the invention of acceleration cancelling hydrophones in 1969 by Hancks et al. (US Patent 3,458,857). However, the use of motion sensors within streamers was considered too noisy to be effective, until 2007 when PGS introduced a dual-sensor streamer and demonstrated that much of the noise on the motion sensors is in the lower frequencies and that denoising techniques could be used to recover the higher end of the spectrum. If the streamers were towed deeper, both hydrophones and gimbaled geophones were deployed in the streamer, and with careful processing, the hydrophone data could be used for the lower frequencies and the geophone data used to fill in the missing frequencies in the ghost notches.

Considerations for integrating motion sensors into streamers

With the advances in modern electronics in terms of power requirements and size, it is now possible to deploy more sensors within a given volume of streamer. In order to acquire useful information from motion sensors within a streamer, the following issues must be understood:

a) noise resulting from transverse wave modes within a streamer under tension,
b) type of sensor to be used,
c) motion sensor orientation with respect to vertical when the cable is rotating during data acquisition.

Transverse wave noise

The strongest noises that affect motion sensor measurements within a streamer are transverse vibrational modes. These vibrational modes propagate at very low velocities and have very large amplitudes. As discussed above, motion sensors within the streamers are extremely noisy and so a primary concern is the attenuation of as much of this noise as possible. Another extremely important consideration is that the signals required for broadband data acquisition must not be compromised and therefore any arrays that are used must be short enough to retain the high frequencies. In order to achieve this, it was decided to use short arrays that would attenuate the higher frequency transverse noise without adversely affecting high frequency reflections. This group was also tailored so that it would optimize the signal to noise ratio of the particle motion channels where it is useful, i.e., within the hydrophone notch bandwidth. The group spacing is 12.5 m, consistent with the current hydrophone receiver groups. Figure 1 shows a F-K plot from several noise records that were acquired during a test campaign. It can be seen that the strong low-frequency noises are clearly not attenuated while the higher frequency noise above 15 Hz is. This enables us to provide good signal content above 15 to 20 Hz.

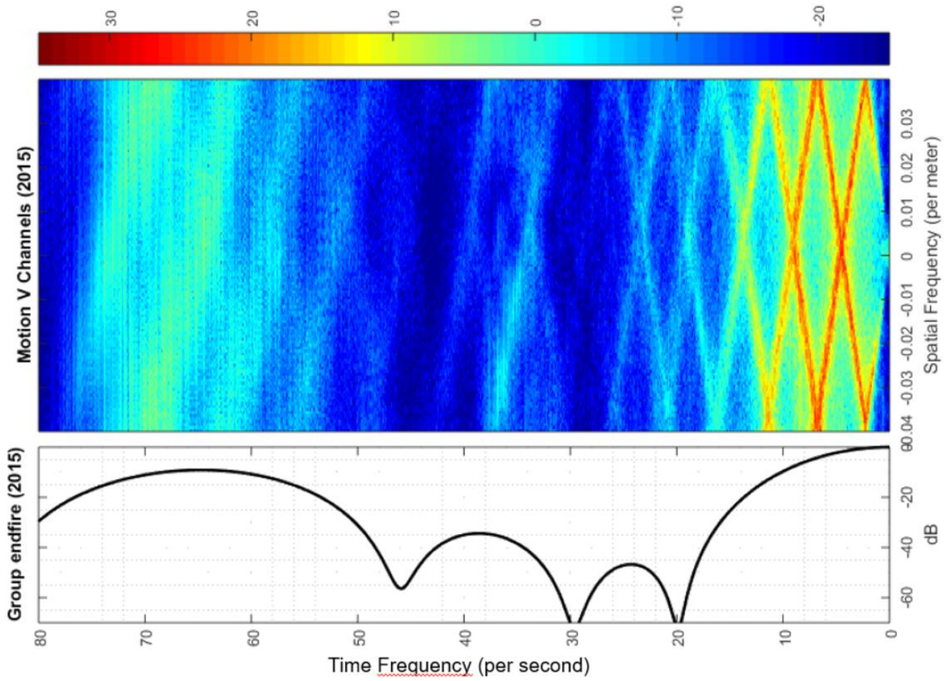

***Figure 1** F-K plot of motion data recorded during tow noise test that shows the effective attenuation of the higher frequencies of the transverse noise by the sensor array.*

Type of sensor

Several types of sensors were considered: gimbaled velocity sensors, MEMS accelerometers that can automatically measure and correct for tilt and fixed accelerometers with separate tilt measurement and correction. With regards to gimbaled sensors an immediate consideration was the noise associated with gimbals. Although these can have quite low noise levels when new, after extensive field use the noise level is frequently seen to increase. Also, because they require some form of damping mechanism that is usually a fluid or oil that is within the chamber, temperature variations that will change the viscosity of the fluid become a concern.

In comparison, MEMS sensors generally require more electronics to be managed. The direct consequence is a step change in equipment cost and reduced reliability that would highly compromise the operational efficiency of a seismic vessel.

Another issue was the cable construction. Our production solid cable construction has a radially symmetrical form, with a central strength member at the core. Retaining this configuration was very important for us to be able to manufacture a streamer at a realistic cost. As a result, the selected sensors were orthogonally mounted analog accelerometers. Separate tilt sensors provide the required information to correct the orientation.

Streamer rotation and sensor orientation

Streamers undergo significant variations in tension during acquisition and these cause rotational or torsional waves to transmit along the length of the streamer. This means that the orientation of motion sensors requires correction to provide true vertical and horizontal measurements. After testing it was determined that the torsional variation within short distances was minimal and that over a receiver group length of 12.5m a single tilt correction would be adequate for that group. In our system this single measurement is made independently at the group center and applied to the recorded measurements. We then get the benefit of being able to accurately design the tilt measurement conditioning adapted to the cable torsional behavior.

New multi-sensor solid streamers in operations

One of the main goals of this design was to provide a cost effective way to record particle motion with streamer cable. Part of the equation is to make sure this new cable has the same operational efficiency as previous generation solid streamers. A full spread of this new cable was first deployed in April 2017 on the CGG vessel Geo Coral. Since that time, the vessel's operational performance and production levels have matched those of vessels equipped with equivalent hydrophone-only streamer.

Data examples

Another key aspect of a multi-sensor solid streamer design is to make sure that the best hydrophone noise performance is preserved, despite the complexity linked with the integration of additional sensors. In the PZ sum process, the hydrophone remains the main contributor to the final quality of the image. In particular, the hydrophone information is commonly used to reconstruct the low-frequency part of the signal in the PZ summation process, as described by previous authors (Tenghamn et al., 2009, Caprioli et al., 2012). In Figure 2, we can observe some hydrophone noise spectral amplitude displays. The new cable exhibits the same noise performance as previous generation hydrophone-only solid streamers. The only visible difference in the low frequency part is due to the different analog low-cut filters (2 Hz for the multi-sensor solid cable vs. 3 Hz for the hydrophone-only solid cable section).

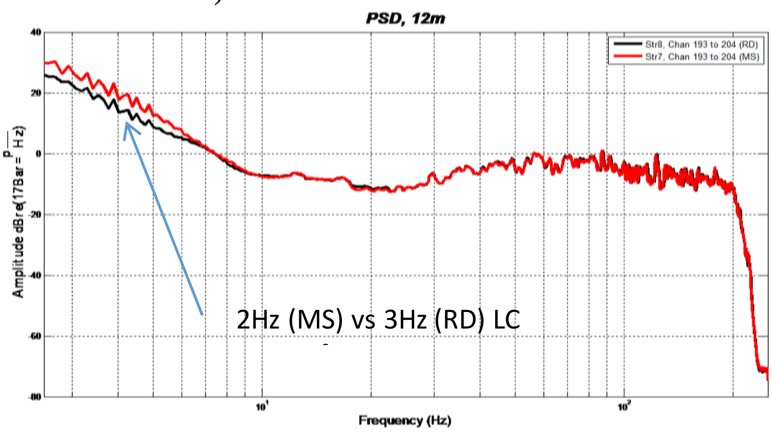

Figure 2 *Noise amplitude spectral display comparing a 3 Hz low-cut hydrophone-only solid cable section (black) to the 2 Hz low-cut hydrophone channels of multi-sensor solid cable section (red). Data recorded at the same time on two adjacent streamers, with the same offset.*

Finally, the benefit provided by the particle motion sensors was assessed by comparing images generated from the same data set, either by using a hydrophone-only deghosting method or a joint deghosting method using both the hydrophone and the particle motion sensor data (Poole, 2018). Figure 3 is a data example after migration, using a hydrophone-only deghosting method. For Figure 4, the same data set was used, but a joint deghosting method was applied, taking advantage of the added information provided by the accelerometers. When focusing on the hydrophone notch bandwidth (from 56 to 64 Hz), it is obvious that the acceleration information is contributing to the overall data quality.

Conclusions

Transverse wave modes are the most troublesome for recording motion sensor information within streamers. For the higher frequencies the design of our array has been specifically tailored to optimize signal to noise ratio within the hydrophone notch frequency bandwidth. This ensures good attenuation of this noise and good signal preservation above 20 Hz. For the lower frequencies, specific care has been taken to preserve the hydrophone performance of state-of-the-art hydrophone-only solid streamers. The combination of acquired vertical motion and pressure sensor data provides broadband seismic signals with good recovery of frequency ranges normally lost within the ghost notches of a streamer equipped with only hydrophones.

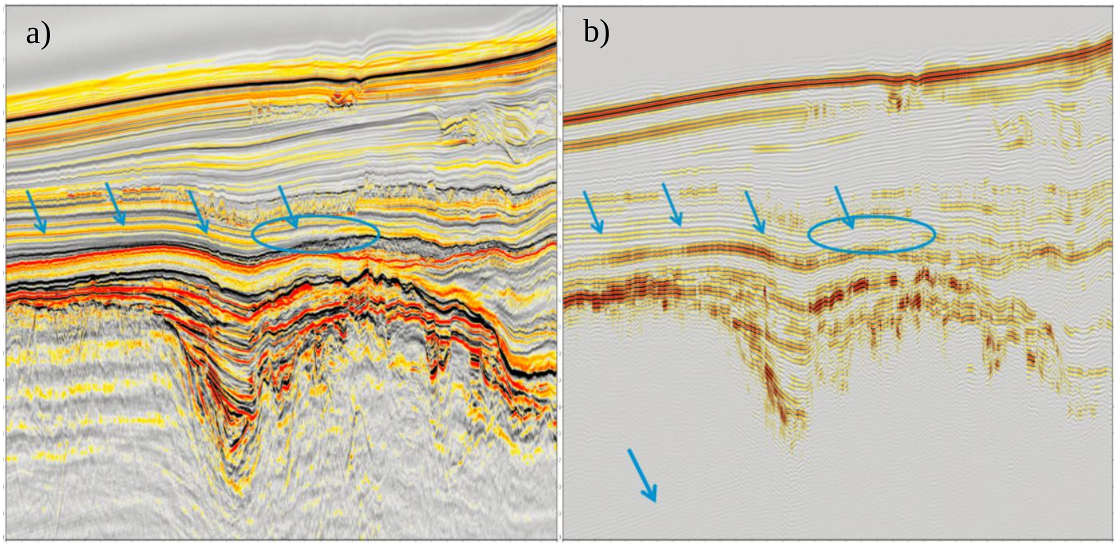

Figure 3 *Data example after migration using hydrophone-only deghosting: a) Full bandwidth, b) Band-pass filter around hydrophone notch (62.5 Hz)*

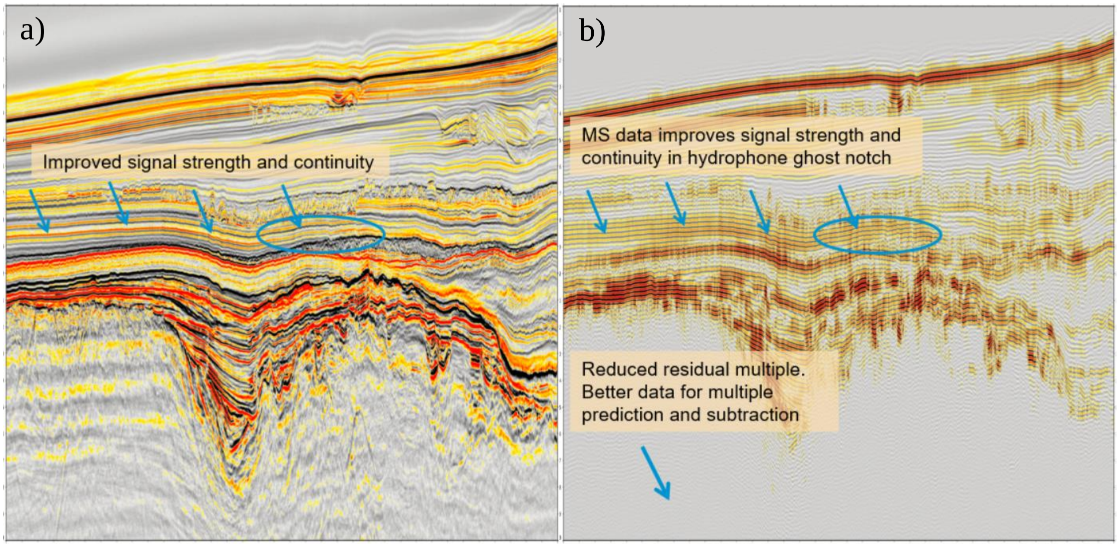

Figure 4 *Data example after migration using joint deghosting: a) Full bandwidth, b) Band-pass filter around hydrophone notch (62.5 Hz)*

Acknowledgments

The authors would like to thank CGG for their assistance in the acquisition and processing of the data, and for permission to publish this work.

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