Tu E 05

Shot to Shot Source Signature Variation Correction

H. Tabti* (Petroleum Geo-Services), J.F. Wisløff (Petroleum Geo-Services), T. Høy (Petroleum Geo-Services), M. Widmaier (Petroleum Geo-Services)

Summary

In this paper we discuss the ability to correct for shot to shot source signature variations and show how this could impact current survey source specifications. Contractual survey specifications define acceptability limits as to which changes can be tolerated based on source wavelet attribute changes. Parts of two acquisition sequences have been acquired with deliberate survey source out-of-spec configurations. The out-of-spec tests included both source dropouts and pressure drop in separate sequences. Shot by shot source signatures have been generated from near field measurements. These were used to correct the seismic data for source wavelet changes including those caused by the out-ofspec pressure and source dropouts. We have demonstrated in this work that changes in the source signature, including changes beyond out-of-spec limits, can be estimated at every shot point and can efficiently be corrected for in processing. Current source out-of-spec limits are possibly too rigid if source variations can be estimated at each shot point and corrected for in processing.

Introduction

In conventional offshore seismic exploration, a marine seismic source is used to repeatedly generate an acoustic pressure wave field in the water column at predefined geographical locations and depth below sea level. The source equipment and the receiver spread are towed by a seismic vessel along predefined survey paths designed to cover a given prospect area. The marine seismic source is in fact a relatively flexible array of individual sources which, under the combined action of the vessel drag, ocean waves and underwater currents, continually move relative to each other and up and down relative to the sea surface. These variations inevitably impact the wave field output by the source from shot to shot (Tabti et al. 2017). Standard processing assumes the same source pulse is generated at every shot point and generally only tolerates known systematic changes between surveys or parts of the same survey. As a consequence, strong constraints are imposed on repeatability of the source output. Despite very tight monitoring of the source equipment, many of the changes are inevitable. In addition, acceptability limits are imposed on which individual source elements can be de-activated (when failing) and which other spare element can be activated as replacement. These are known as source dropout specifications and can sometimes lead to costly survey down time when seismic operations have to be suspended and the source string brought on deck to fix or replace failing source elements. What if any changes in the source output, including those due to source dropouts, can be predicted and corrected for? This is precisely what shot by shot far field estimation from near field measurements aims to achieve. This has the potential to bring in much needed flexibility when conducting marine seismic surveys, increasing efficiency and reducing frequent and costly maintenance during production time. Relaxing on out-of-spec limits can allow for planning such maintenance in a more optimal manner.

Marine source variability and acceptability specifications

Repeating the source output from a source array means that the output from each individual source element must be repeated. An individual source element is made of a pneumatic chamber which is filled with air up to some predefined operating pressure (generally 2000 psi). When one of the predefined geographical source positions is attained, the high pressure air in the pneumatic chamber is instantly released in the water column creating a very rapidly expanding air bubble which, after reaching its maximum, contracts back to its' minimum starting another of several cycles in an amortized oscillating process. These bubble oscillations are controlled by the differential pressure between the air inside the bubble and the hydrostatic pressure in the surrounding water. The dampening is controlled by an energy dissipation process which makes each successive oscillation weaker and smoother. This process generates a pressure wave field that propagates in all directions away from the source at the speed of sound in water (approximately 1500 m/s). Figure 1 shows examples of acoustic pulses that would be generated by a single pneumatic chamber for 2 different volumes operated at the same pressure of 2000 psi. The acoustic wavelet is characterized by the strength of its' initial peak, known as the primary peak, and the ratio of the latter to the first secondary peak known as the first bubble peak (or just the bubble peak as the later oscillations are not generally used to characterize the source output). In addition to the primary peak and the peak-to-bubble ratio, the main bubble period is also used to characterize the source output in the time domain. Other attributes are calculated in the frequency domain such as the average and the maximum spectrum within a predefined frequency range. As can be seen in Figure 1, different volumes produce different wavelets i.e. different primary and secondary peaks and different bubble periods.The acoustic output from individual air chambers depends on several factors. At constant temperature the bubble period T can be predicted by the widely used Rayleigh-Willis formula (Willis, 1941):

$$T = Const \, \frac{P^{1/3} V^{1/3}}{\left(P_{atm} + P_{hyd}\right)^{5/6}} \; , \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \quad (1)$$

Where $Const$ depends on source element design, P is the operating pressure, V is the volume of the chamber, P_{atm} is the atmospheric pressure and P_{hyd} is the hydrostatic pressure which is directly proportional to the source depth below sea level. The peak amplitude can also be approximated by an empirical formula (Nooteboom, 1978):

$$A \sim P^{2/3} V^{1/3} \qquad \text{(2)}$$

Notice that pressure and volume changes will affect both the amplitude and period of the source wavelet. These formulas are generally invoked to set acceptability limits on source output variability (peak amplitude, peak-to-bubble ratio and average and max dB spectral deviation).

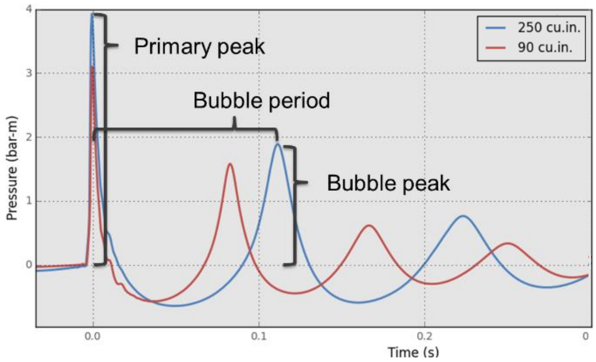

Figure 1 *Pressure output wavelets from two different pneumatic chambers.*

Test	Shot	Dropout elements	Pressure
1.1	1-200	1-10, 2-4, 2-9, 3-3	2000psi
1.2	201-400	2-5	2000psi
1.3	401-600	2-5, 3-5	2000psi
1.4	601-680	1-1, 1-7, 2-5, 3-5	2000psi

Table 1 *Summary of the source dropout test.*

When individual pneumatic chambers are arranged in clusters and single elements along strings within a source array of several strings (Figure 2), the behaviour of the source can be very different from the simple formulation above. The strong interaction between neighbouring source elements and with the mirror source (i.e. the combined sea surface ghosts) leads to strong variations in the source output from shot to shot as a result of continues changes in the relative positions and depth of the individual source elements. Therefore, controlling the source output from the full array can be very complicated. If the emitted source wave field can be estimated at every shot point, the requirement for maintaining the same source wavelet, which is the same as maintaining the same source geometry, depth, volume, pressure and timing, can be relaxed.

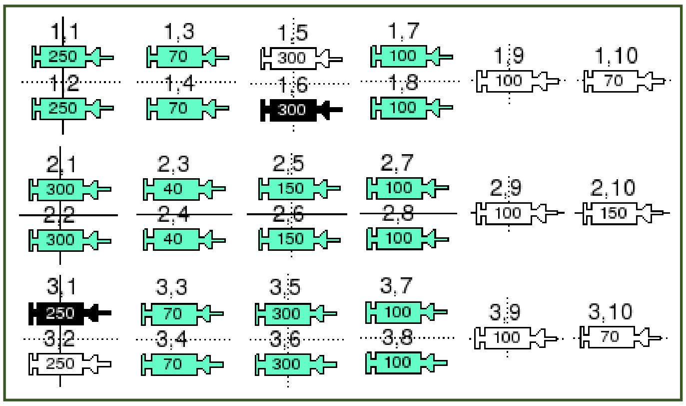

Figure 2 *4100 cubic inch source array with 3 strings.*

Test	Shot	Pressure
2.1	1-240	1900 psi
2.2	241-380	1825 psi
2.3	381-500	1700 psi

Table 2 *Summary of pressure drop test.*

Volume and pressure illegal drop test

In order to test the capability to estimate the emitted pressure wave field at every shot point from near field measurements and the ability to use these to correct for source variations beyond todays accepted limits, a deliberate out-of-spec volume and pressure drop test has been acquired. The acquisition setup used a dual-source configuration alternating between the port and the starboard source arrays (flip-flop acquisition). Each source is a 4100 cuin (cubic inch) array comprising 3 strings with clusters and single pneumatic chambers of different volumes (Figure 2). Green colour indicate clusters and white singles. Note that source chambers 1-6 and 3-1 (in black) are spare –inactive- elements.

In the first test, parts of an acquisition sequence towards the end of the line have been deliberately acquired with various 'illegal' source dropout combinations summarized in table 1. The starboard array was kept unchanged while one or several source elements have been de-activated on the port array to make it out of spec according to survey specifications.
Shot by shot far field signatures have been generated on-board the vessel by the method described in Tabti et al. (2017). The derived signatures (shown on Figure 3) reflect the expected behaviour from such dropout combinations both in amplitude and phase characteristics. Test ranges are delimited by the yellow vertical dashed lines on figure 3. Different dropout combinations produce different changes in the signature. For example, the first dropout combination produces almost only an amplitude change in the peak, while the last dropout (to the far left) affects both peak and bubble.
A pressure drop test has been acquired towards the end of another sequence where manifold pressure has been dropped in steps from the nominal 2000 psi down to 1700 psi, decrementing by ~100 psi at each step. Pressure drop is not instantaneous and requires several shots before it is stabilized at the desired pressure. The transition is therefore relatively smoother between successive pressure levels.

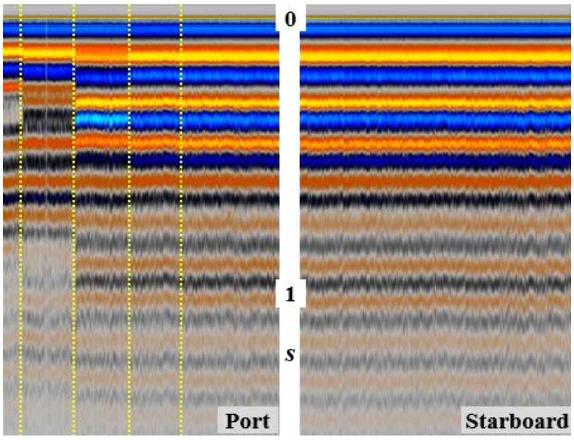

Figure 3 *Shot by shot far fields source dropout.*

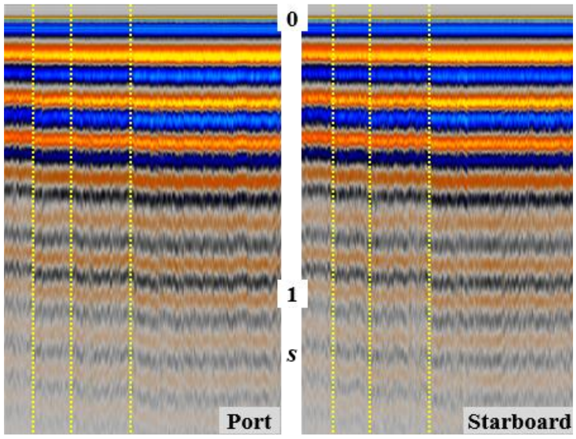

Figure 4 *Shot by shot far fields pressure drop.*

Also here the corresponding shot by shot far field signatures reflect the expected behaviour (Figure 4). Again, test ranges are delimited by the yellow vertical dashed lines. Note that manifold pressure drop affects both source arrays. Both peak and bubble are affected by the pressure drop as would be predicted by equations 1 and 2. As expected, the last, 1700 psi, test (to the far left) shows the biggest change.

Shot to shot signature variation correction

The derived shot by shot far field signatures have been used to correct the seismic data for changes in the seismic wavelet caused by the out-of-spec drop tests above as well as for the many other natural variations caused by the dynamic acquisition conditions as described above. Figure 5 shows a raw ghost-free near offset trace gather (flattened sea bottom reflection) before (top) and after (bottom) the application of signature variation correction for the sequence containing the illegal source dropouts. On the unprocessed near offset trace gather (top), we can clearly distinguish the shot ranges with the source dropouts similar to the shot by shot signature display on Figure 3. Outside the dropout shot ranges the seismic wavelet character is similar between the port and the starboard arrays. After applying the shot to shot variation corrections derived from the generated shot by shot signatures, the signature shape becomes very similar on the full line between the port and the starboard near offset gathers and the more natural shot to shot wavelet variations within each gather are also corrected for.
Figure 6 shows similar near-offset trace displays from the pressure drop test with ghost-free raw data on top and the same corrected for shot to shot variations at the bottom. Here again we can clearly distinguish the shot ranges with pressure drop on the top display on both arrays towards the end of the line (towards the left). After signature variation correction (bottom display) the signature changes caused by the pressure drop as well as other natural changes are strongly attenuated and the wavelet shape shows good continuity within each array as well as good similarity between the two arrays.

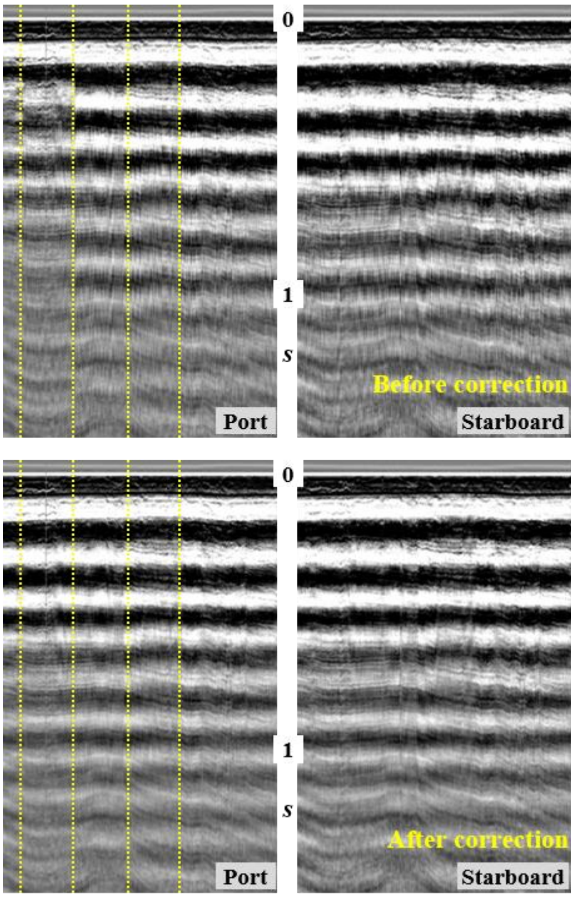

***Figure 5** Source dropout: near offset trace.*

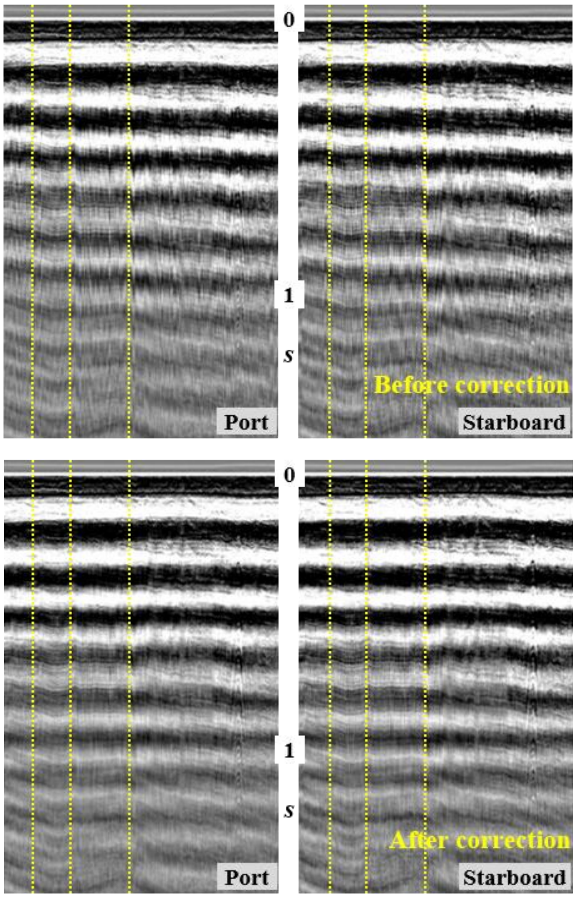

***Figure 6** Pressure drop: near offset trace.*

Conclusions

Parameters such as pressure, volume and depth combined with towing configuration, vessel speed, source timing and weather conditions all contribute to create inevitable variations from shot to shot in the emitted source wave field. Contractual survey specifications define acceptability limits as to which changes can be tolerated based on source wavelet attributes. We have demonstrated in this work that these changes in the acoustic output, including changes beyond out-of-spec limits, can be estimated at every shot point and can efficiently be corrected for in processing. This can potentially open the possibility for pushing current out-of-spec limits with, as a consequence, more flexibility, better efficiency and less down time when conducting marine seismic surveys.

Acknowledgements

We thank PGS for the permission to publish the data. We would also like to thank the PGS vessel crew members who conducted the test and generated on-board the shot by shot signatures used in this work

References

Nooteboom J. 1978. Signature and amplitude of linear airgun arrays. Geoph. Prospecting 26, 194-201

Tabti H., Høy T., Wright A., Barker D., Drossaert F., 2017. Shot by shot source wave field estimation. 79th Conference and Exhibition, EAGE, Extended Abstracts: Tu A4 07.

Willis H., 1941. Underwater explosions, time interval between successive explosions: Technical report, British Report WA-47-21.