Sea trial of a low frequency enhanced pneumatic source

Steve Chelminski, Fred Chelminski and George Steel, Low Impact Seismic Sources; Shuki Ronen, Low Impact Seismic Sources and Stanford University; Guido Baeten, Tianrun Chen, Keith Hunt, Maksym Kryvohuz, Henning Kuehl, Boris Kuvshinov, Hamish Macintyre, Matt McDonald, Francesco Perrone, René-Édouard Plessix, Zijian Tang and Fons ten Kroode, Shell*

Summary

A new pneumatic seismic source with a resonance frequency of 2.8 Hz has been built and tested during an OBN sea trial in the Gulf of Mexico. Data from the new source demonstrates that low frequency refracted signal can be recorded for offsets up to at least 45 km. The low frequency signal from the new source is very much improved compared to data from an array of conventional airguns.

Introduction

Airguns have served the seismic industry well since they replaced explosives over half a century ago. Receiver technology has been upgraded more than source technology in this period. In particular, receivers now record much lower frequency content which is important for building velocity models, imaging under complex overburden such as sub-salt and sub-basalt, improved resolution, and building blocky reservoir models (ten Kroode et al, 2013). Fifty years ago seismic sources were producing lower frequency signal than receivers were able to record. Today the opposite is true. Increased demand for low frequency signal is a motivation to evolve from airguns to new source technology. Another motivation is reducing environmental impact. Airguns replaced explosives which generated a lot of high frequency sound waves. Airguns were designed to also generate high frequencies that are typically scattered and attenuated in the overburden. High frequency signals are typically not required for targeting most hydrocarbon accumulations but are an objective for drill site surveys. The higher airgun frequencies are believed to have an undesirable environmental impact.

In this paper, we present the results of the first sea trial of a new seismic source with enhanced low frequency content and reduced environmental impact. This new source, the Tuned Pulse Source (26,500 cui source), is shown in Figure 1, where the launch of the source during the sea trial, using a boom setup and a float, is photographed.

The Tuned Pulse Source

The new low frequency source is pneumatic. Like airguns it releases high pressure air which forms a bubble that oscillates and radiates acoustic waves. Unlike airguns, the pressure in the new source is lower (1,000 psi) and its volume can be much larger (Ronen and Chelminski, 2017). We tested a source that was 7.3 meters long (Figure 1) and had volume of 26,500 cui. Figure 2 shows the bubble just after the source has been fired. The oscillating bubble has a resonance frequency of 2.8 Hz and its maximum radius is close to 2m.

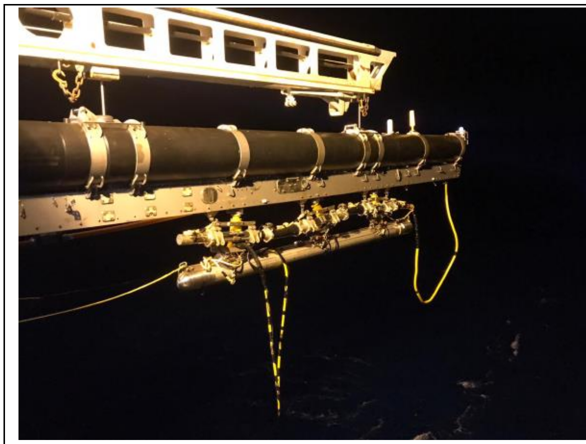

Figure 1: The new source during deployment in the Gulf of Mexico. The source itself is the lower steel cylinder. The upper black cylinder is the float. Below the float we can see the steel keel. Between the keel and the source is a semi-rigid-bundle where near field hydrophones and other sensors are mounted, which is unbundled on source deployment.

Figure 2: The new source just after firing. The maximal bubble radius is almost 2 meters. To indicate the scale, note that the length of the 26,500 cui source that is visible to the left in this picture is 7.3 m.

Figure 3 shows a spectral comparison between a conventional 5,110 cui airgun array and the 26,500 cui source. In the mid band (10-50 Hz), the spectrum of the large source is up to 12 dB smaller than the array. Typically, the conventional air gun arrays provide an abundance of energy in this mid band (Laws et al, 2018), and this reduced amplitude for the 26,500 cui source is preferable. In the 0-3 Hz band, the amplitude of the 26,500 cui source is approx. 20 dB larger than the airgun array. The rate of decay in amplitude from the resonance frequency towards the low frequency end of the spectrum is approximately 18 dB/octave. This rapid decay illustrates the importance of a low resonance frequency for an efficient low frequency source.

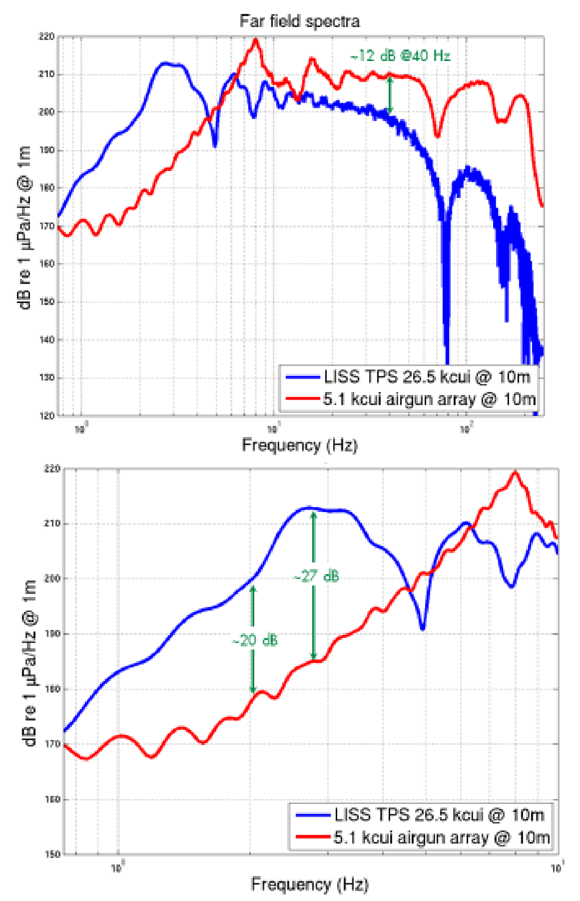

Figure 3: Estimated far field spectra for the 26,500 cui source (blue) and a conventional 5,110 cui airgun array (red). Top: full frequency band, bottom: zoom-in for the 0-10 Hz frequency band.

The sea trial

Following the manufacturing of the 26,500 cui source, and a series of lake tests, a sea trial was executed that successfully satisfied both operational and geophysical objectives. Operational objectives included the evaluation of deck handling, launch and retrieval, safety aspects, towing, gun control, and maintenance of the source. On the geophysical side, the purpose of the sea trial was to compare the low-frequency performance of the 26,500 cui source with a conventional air gun array, and to determine the propagation characteristics of the low frequencies as a function of offset.

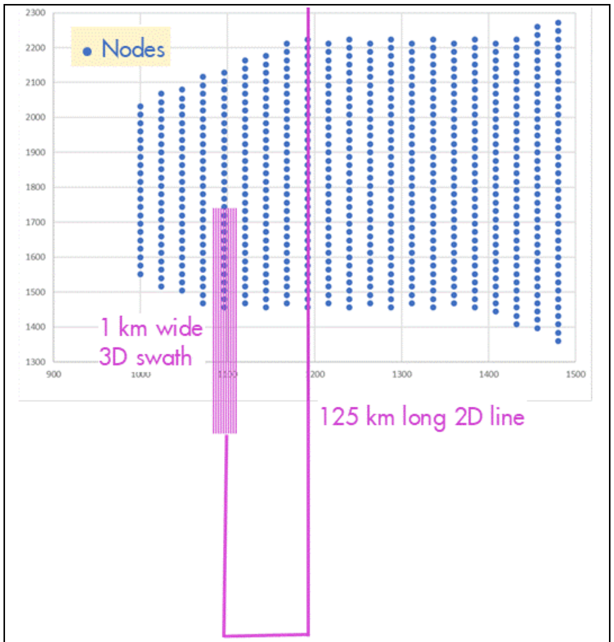

Figure 4: The shot lines for the sea trial, and the nodes that were deployed as part of the Engagement survey.

The sea trial was conducted in the Gulf of Mexico in late August/early September 2020, as part of the 2020 Engagement OBN multi-client survey shot by TGS and WesternGeco. In the Engagement survey, a total of 2066 OBN nodes were deployed on a 1200 x 1200 m grid (Fig. 4). A dedicated source vessel, the Sanco Atlantic, was used to deploy the 26,500 cui source. Following lake testing we deployed the source at a depth of 10 meters below the surface. Three near field hydrophones (NFH) were deployed on a semi-rigid-bundle 5 meters above the source. The distances between the individual NFHs and the ports of the source were 5.7, 6.3 and 7.6 m, respectively. All operational tests (rigging, towing, gun control etc.) were concluded successfully, and both the towing properties and the ease of handling of the source which has a length of 7.3 m exceeded expectations.

The sea trial was shot over a period of 10 days. The shot effort was divided in two parts:

- A 2D line of length 125 km, with 100m shot interval.

- A 3D swath of dimensions 25x1 km, containing 10 shot lines at 100m separation and 100m shot point interval.

The purpose of the 2D line is to acquire very long offset data suitable for 2D imaging and inversion tests using the extra low frequency output. It is understood that the complex geology in the area is not well suited for 2D approximations, but as a minimum requirement the aim was to investigate the kinematics and strength of the diving waves and refractions. In addition, 2D data for both the 26,500 cui source and the conventional airgun array were acquired and a comparison between the two source types made. The main purpose of the 3D swath was to quantify the impact of stacking on the node recorded data quality, with emphasis on the low end of the frequency band. Initial results of the 2D line and the 3D swath are shown in the next section.

Results

In this abstract we show the data with no preprocessing except bandpass filtering and (for the 3D swath) stack. Designature and deblending have not been applied to the data shown in this abstract. A representative Common Node (CN) gather for the 2D line is shown in Figure 5.

A 2-3 Hz lowpass filter was applied to the CN gather to illustrate the strength of the low frequencies. Results are shown for both the 26,500 cui source and the conventional 5,000 cui production airgun array. Note that the results for the array were extracted from the production survey which was shot using a dual vessel, triple source geometry with shots firing at 8s intervals on each vessel independently. With a trace length of 24 seconds, there is a significant amount of blending in the production data. It is observed that the 26,500 cui source data also has some blending noise, generated by seismic interference originating from a survey in the vicinity of the Engagement survey area. The blending noise is reduced in the 2-3 Hz bandwidth since airgun arrays typically have low amplitude levels in this band. Despite the blending noise, the first arrival energy can be clearly identified on both data sets. The 26,500 cui source data not only shows direct arrival and salt refractions, but also higher-velocity events which originate from sub-salt formations down to basement and have velocities exceeding 4500 m/s, as indicated in the figure. The corresponding Common Nodal production data are dominated by the direct arrival and noise events, including blended noise, but no coherent high velocity events are observed in this data. Based on the spectra shown in Figure 3, this is not surprising as we expect the array results to be 20 dB below the 26,500 cui source results in the bandwidth under consideration.

A comparison between a 3D swath node gather and a synthetic node gather using an initial velocity model is shown in Figure 6. The 3D swath was acquired with the objective to quantify the improvement stacking can provide for the low frequencies. As an initial assessment of the impact of stacking, a simple moving average filter was applied to the data. For each source point on the central line of the swath, a stacking area with a size of 1 km^2 centered around the source location was selected. For the 0-4 Hz frequency band that is considered in this example, the stack over a 1 x 1 km area corresponds to summing 100 traces, yielding a 20 dB S/N improvement over the raw nodal data if the square-root law is assumed to hold for the S/N. This stacking procedure is expected to somewhat reduce amplitudes of events at the higher frequencies (close to 4 Hz), but is applied here to illustrate the S/N benefits for 3D acquisitions where, in particular, at the low frequencies stacking can be performed over a relatively large number of traces. Comparing the synthetic gather with the real data, it is observed that there is global agreement in the sequence of refractions and diving wave events above the first arrival energy. When viewed in more detail, there are discrepancies but these can at least partly be attributed to the inaccuracies in the velocity model that was used in the generation of the synthetics.

Conclusion

A new seismic source with significantly better low frequency content than conventional airgun arrays has been tested in a Gulf of Mexico sea trial. Results on a raw single node gather show that refracted events and diving waves can be identified in the 1-3 Hz frequency band for offsets up to at least 45 km. Initial results on a 3D swath demonstrate the potential for further S/N improvement by using the redundancy that is available in the data, and also show a global agreement with synthetic data produced using an initial velocity model. The new source is a promising tool for use in low frequency acquisitions such as Long Offset Low Frequency surveys, and is expected to increase the quality of FWI and Quantitative Interpretation.

Acknowledgements

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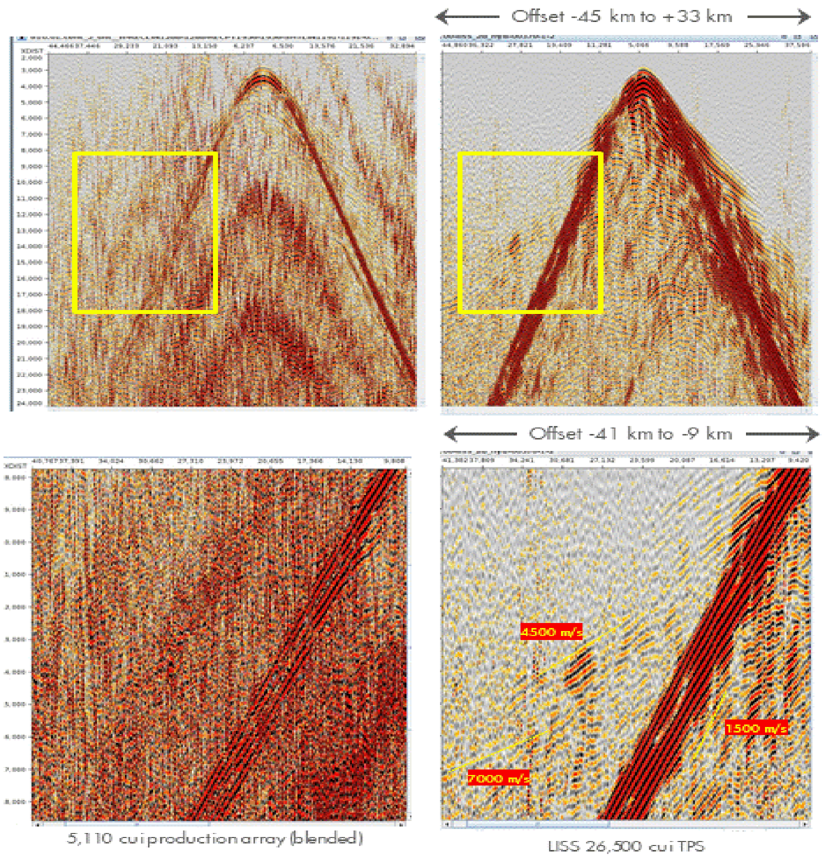

Figure 5: Common Node Gather from the conventional airgun array data (left) and the 26,500 cui source (right).
Top: offset range 45 to -33 km. Bottom: a zoom-up of the yellow frame–offset range 9 to 41 km.

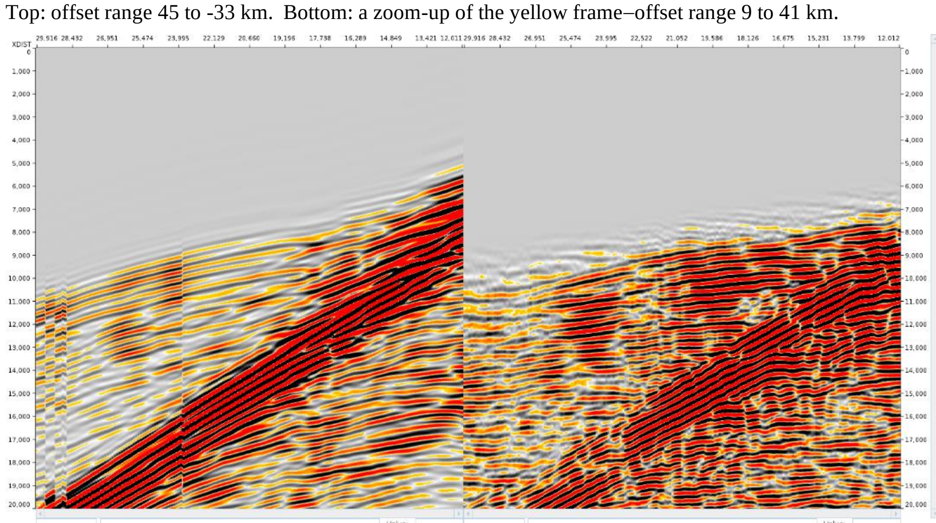

Figure 6: Common Node Gather from the 3D swath data, in the offset range 12-30 km, for a 0-4 Hz frequency range.
Left: synthetic gather using an initial velocity model. Right: Real data after S/N was improved by stacking over a 1 x 1 km area.