Tuned Pulse Source—a new low frequency seismic source

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Summary

The Tuned Pulse Source is a pneumatic source designed to operate with low-pressure air. It releases a large volume of air into the water over a controlled time generating a pulse with a long rise time and a bubble oscillating at low frequency. Compared to air guns, the TPS has much stronger low frequency content, down to 1 Hz, and reduced high frequency content. The low frequency content makes the TPS significantly better than airguns for applications such as sub-salt and sub-basalt imaging, building velocity models with full waveform inversion, and building blocky reservoir models. The reduced high frequency content makes the TPS environmentally friendlier than airguns.

Introduction

When the technology of producing oil from the ground was developed the then new earth-oil industry saved many whales from extinction. That was about 150 years ago. Until then, oil-industry meant whaling. Whale oil was expensive because it was labor and risk intensive. It was therefore used sparingly, mainly for lubrication of machines, mostly coal-powered steam engines. Even with such limited use, many whale species were on their way to extinction. Earth-oil made whale-oil obsolete. It started of course onshore. As the oil industry went offshore, so did seismic surveys, using chemical explosives as seismic sources. About 50 years ago pneumatic seismic sources replaced explosives.

Explosives were good sources but were dangerous to their operators and harmful to the environment. When pneumatic sources started, operators of seismic crews wanted them to be as similar as possible to explosives as acoustic sources. There were a few consequences to this requirement. One was that the name Air Gun was found to be best for marketing. The second consequence was that Air Guns were deployed in arrays of a large number of small guns. Some people argued for a small number of large guns. But they lost. Large-numbers of small-guns were more similar to explosives. People were telling the salesmen who were selling Pneumatic Acoustic Repeaters (PARs): "Okay we'll buy some Air Guns. We don't really need them. Dynamite is a better source. But we had some accidents and in some places we may not get permits. So we need a few Air Guns so we can operate where we can't permit Dynamite". There was another reason for the victory of many-small-guns on few-big-guns. At the time, the bubble pulses that follow the main pulse was considered a huge problem. The data processing that was available at the time air guns were introduced did not enable turning the bubble into signal. It was noise. The third consequence of the requirement to make pneumatic sources similar to explosives was to design them to operate with as high pressure as practical. So they were designed to operate with air compressed to 3000 PSI with a shuttle that travels a certain acceleration distance to be moving rapidly before one or more ports start opening and expose high-pressure air to the ambient pressure water. The acceleration distance allows the shuttle to be already moving fast when the ports open reduces the rise time and makes the PAR, now called a Gun live up to its name.

Following the early introduction of air guns, operating at 3000 PSI it was found, interestingly, that operating the same guns at 2500 PSI and then at 2000 PSI did not compromise the geophysical quality. It did reduce the wear and tear. So within a decade or two, all guns were operating at 2000 PSI. However, the engineering design for 3000 PSI and the acceleration distance continued unchanged. Of course, more significant changes than the pressure of the air happened in the seismic industry in the last 50 years. Data processing, enabled by great advances in digital computing enabled great progress in imaging, in building velocity models, and in wavelet processing. Among other things, data processing enabled turning the bubble pulses from noise to signal. Nevertheless, the same airguns, deployed in arrays of many small guns continued to be standard. There was no significant attempt to modify airguns following a review of the requirement that they should be "just like dynamite".

At times there has been a disconnect between the people who knew how to process data and the people who designed seismic sources. Seismic source R&D rarely went in the direction of increasing low frequency content and reducing high frequency content. Instead source R&D efforts were invested to eliminate the bubble, which continued to be viewed as a problem although there was a data processing solution that turned it from noise to signal. Arrays continued to be designed with a high "Peak-to-Bubble Ratio" objective, and new guns with less bubble pulse were designed: the gas injection (GI) gun and the water gun. GI and water guns did not succeed because eliminating the bubble also eliminated the low frequency content. The original airgun continued as the preferred source, with improved data processing supported by improved modeling and with the use of near field hydrophones (NFH) to record signatures as they vary from shot to shot to provide good signatures to data processing.

If we stopped using air guns and replaced them with sources that compromise the low frequency content, we would compromise subsalt and sub-basalt imaging, full-waveform-inversion (FWI), and inversion of seismic data to blocky earth models.

While the seismic industry has continued to use airguns pretty much as they were 50 years ago, offshore receiver technology has progressed very significantly. First in quantity: from a single 2.4km-long- 96 channel- fluid-filled streamer to up to 20 streamers, up to 12 km long, up to 320 channels per km. Also in quality: 24-bits solid streamers reduced noise and enabled data processing to not only turn the bubble to signal but also solve the problem of the surface ghost. The surface ghost is the reflection of the source from the surface of the water. It is noise because it generates a spurious “ghost” event. Before the ability to fix this problem in processing, streamers were deployed very shallow to minimize the ghost effect by reducing the lag time. This was a solution but it increased the weather downtime, and compromised the low frequency content. With 24 bit solid streamers and improved data processing, streamers started to be deployed deeper.

Another significant advance in streamer technology was the ability to shoot from separate vessels. It was developed for undershooting platforms in reservoir monitoring, and then it enabled Wide Azimuth Towed Streamers.

A very significant development in receiver technology was the introduction of ocean bottom nodes. OBNs were first suggested for the purpose of recording shear waves and to undershoot obstructions, but it was later found that they provide higher quality P-wave data also in unobstructed areas. OBN provide broader band than any streamer and fuller azimuth than any wide azimuth towed streamers (WATS or WAZ or so called full azimuth FAZ). The OBN geometry of dense shot carpets is better for wave-equation imaging because the OBN common receiver gather is a well sampled domain of a physical wavefield while streamer common shot gathers have narrow extent and poor sampling in the cross-line direction.

With all the above advances in receivers, we are still using 1960-s source technology. Why? Good question.

Tuned Pulse Source

Recently, Chelminski took the challenge of designing sources with improved low frequency and reduced high frequency content. One result was the Tuned Pulse Source™ (Pat. US 8,971,152 B2 and Pat. Pub. US 2017/0108599). The TPS uses a cup shaped flange and extended ports that go almost 360° around the operating housing. Unlike air guns, no cavitation generating jets of water and then thin jets of air are produced. The TPS expanding bubble avoids high frequency and radiates the energy of the expanding air as low frequency waves. The TPS thus emits less high frequency acoustic energy that has little or no geophysical utility for exploration and reservoir model building. The length of the firing chamber tunes the pulse. The longer rise-time increases the low frequency content and decreases the slope and the high frequency content.

In addition to the technical changes, an important change is that TPS is not named Gun. It is an evolution of the 1960-s pneumatic acoustic repeater that became to be called a gun by people who wanted PAR to be “just like dynamite”.

Figures 1 and 2 show a comparison of modeled signatures of an air gun, a single TPS of 9600 cubic inch, and a cluster of 7X20 thousand cubic inch TPS.

Upgrading from airguns to TPS

Upgrading from conventional airguns to TPS should have a small impact on seismic operations. Relatively minor modifications to compressors, to umbilicals, and to source control systems. Seismic crews will be able to upgrade from Airguns to TPS with no or little delay. Also, minor changes to data processing are needed. The bubble is not moving laterally while radiating seismic waves so there is no need for source motion correction in processing.

As TPS is a large PAR, current operational and processing technologies that were developed for airguns can be used.

One nice feature of the TPS is that fewer elements are needed per array. Airgun arrays typically have 3 sub-arrays each with about 10 active guns. The TPS will fit under a single float as a single sub-array with just 3-7 sources. Thus simplifying deployment, retrieval, source steering, and reducing variations from shot to shot that are mostly due to sub-arrays drifting cross-line.

Lake test data acquisition

We tested a small scale Low Pressure Source (LPS) in Seneca Lake (Figure 3). We had two firing chambers: a 50 in^3 and a 600 in^3. The large volume was shot at pressures varying from 200 to 1000 PSI, and the small volume from 500 to 2000 PSI. Data recorded by near field and far field hydrophones (NFH and FFH). An NFH was tied 1 meter above the LPS and recorded data at 0.5 millisecond sampling interval (1 KHz Nyquist frequency). The FFHs were a vertical array of 24 hydrophones. The nearest one was 75m below the LPS and the furthest one was 121 meter away; 2 meter vertical interval between hydrophones. The FFH, with Δt=31.25 microsecond sampling interval (32KHz sampling rate) provided excellent data up to its Nyquist frequency of 16KHz. Over two days we recorded about 300 shots. Shots at the same depth, volume, and pressure were repeated 3-6 times to test repeatability. Some of the data are shown in Figure 4.

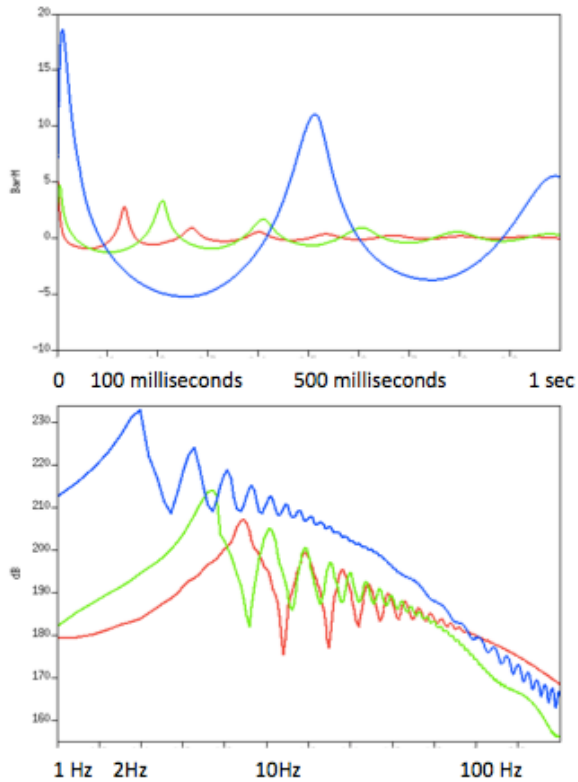

Figure 1. Time domain (above) and frequency domain (below) modeled signatures of a conventional airgun of 548 in^3 (red), a TPS of 9600 cu in^3 (green), and a 7X20K in^3 TPS cluster (blue). In the time domain, note that the sound pressure level of the 548 in^3 air gun and the 9600 in^3 TPS are similar at about 5 BarM. The maximal SPL of the 140 K in^3 cluster is only factor 4 larger at 18 BarMeter. In the frequency domain, note that at 1 Hz, the cluster of 7X20Kci TPS is 30 dB stronger than a single 10K TPS. At 2 Hz, the 9600 TPS is 12 dB stronger than the airgun.

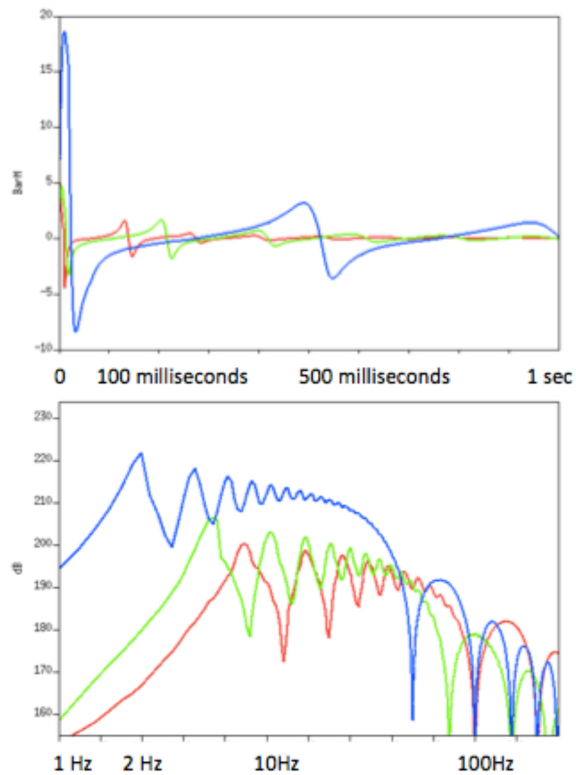

Figure 2. Ghosted vertical signatures. The airgun of 548 in^3 (red) is modeled at 7.5 meters, the TPS of 9600 in^3 (green) is at 10 meters, the 7X20K in^3 TPS cluster (blue) is at 15 meters.

Lake test data processing

We extracted and analyzed several attributes from the Seneca Lake data. Here we show two key attributes: the slope, which is how fast the pressure rises is an important indicator of environmental impact as direct damage to marine creatures. Conventional airguns with acceleration distance and at 2000 PSI have slopes between 1.5 and 3 BarM/millisecond. At low pressures the slopes are much lower (Figure 5).

Conclusion

The Tuned Pulse Source will produce less high-frequency noise and more low-frequency signal, expanding the seismic band on the low side to 1 Hz and reducing the emission of high frequency waves that are useless for deep targets due to attenuation and scattering in the overburden.

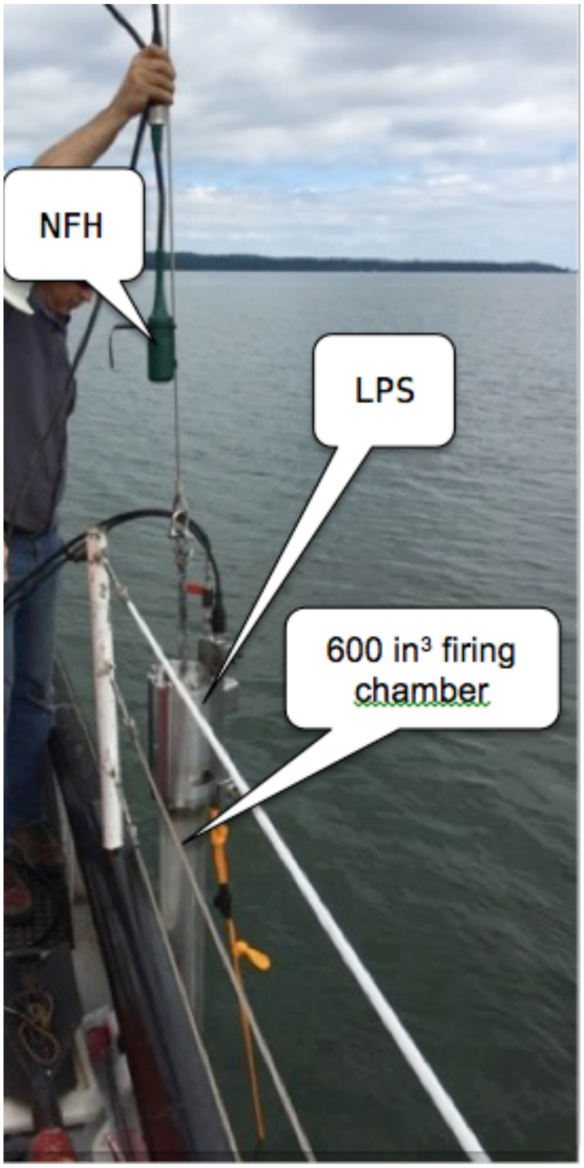

Figure 3. LPS deployed in Seneca Lake. A 600 in^3 firing chamber is hanging vertically below the main housing of the source. Above the source, there is a (green) near field hydrophone. Below the source, already in the water (on an orange nylon rope) there is a vertical array of 24 far field hydrophones.

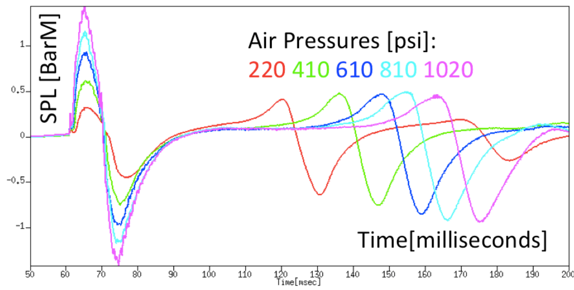

Figure 4. Far field hydrophones data for 600 in^3 Low Pressure Source deployed at 7.5m. Note that the rise time is independent of the pressure. The maximal Sound Pressure Level, the bubble period and the slope depends on the pressure.

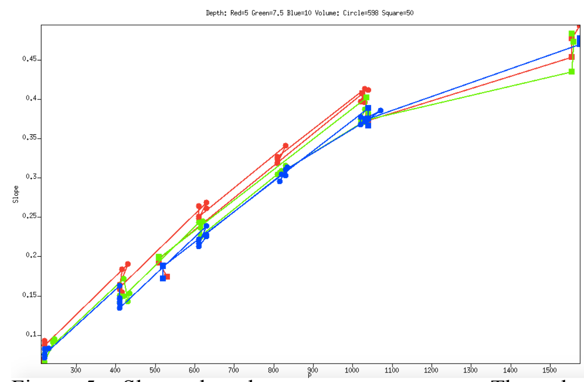

Figure 5. Slope plotted vs. source pressure. The color indicates the depth: red is 5m, green is 7.5m, and blue is 10m. The shape indicates the volume: 600 in^3 is circles, 50 in^3 is squares. The slope is a measure of environmental impact. The slope is independent of volume and is proportional to difference between initial air pressure and ambient pressure. At a source pressure of 600 PSI the slope is 0.2 to 0.26 BarM/millisecond.

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