**Developing a Novel Marine Vibrator System**

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# Abstract

**This paper, and its accompanying presentation is a report on the development and testing of the BASS marine vibrator system. Through this work we showcase marine vibrators as a viable alternative to conventional airgun-based sources both from an operational, environmental and a geophysical perspective.**

# Introduction

Seismic vibrators have been used on land since the early days of seismic exploration. However, their use at sea has been more limited. According to Landrø and Amundsen, (2018) marine vibrator sources were first adapted from land vibrators in the late 1960s. See for example Brown and Fair, (1967).

During this early period Conoco cooperated with several companies including Olympic Geophysical and Ray Geophysical, and later Seiscom as the main leaders in the seismic industry,

At that time marine vibrators provided a good signal, but the vibrator signal length of 10–12 seconds followed by a listening period of 6–8 seconds made the method a bit ineffective compared to the alternative airgun-based method. Furthermore, vibrators systems were error-prone resulting in significant downtime. The result of this was that the seismic industry relatively quickly switched to using airguns, which since the early 1970s, have dominated the market.

However, today there are three key drivers for marine vibrators. They are:

Improved survey efficiency

Improved seismic imaging.

A percived reduced environmental impact

This has resulted in a renewed interest in this source technology, and is the background for the work presented in this abstract.

Marine seismic vibrators emit their energy spread out over time, as opposed to airguns, which emit the energy in a single, high-intensity pulse. This ‘soft output’would give the marine vibrator an environmental advantage even if the total acoustic energy emitted was the same (Southall et al., 2007; LGL and MAI, 2011; Southall et al., 2019). A second environmental advantage stems from our ability to control the energy spectrum of the source. The spectrum can be tailored to be the minimum needed to satisfy the imaging requirements (Laws et al., 2018a). Control of the spectrum also allows marine vibrators to only emit energy within the seismic band [3-150] Hz, thus avoiding unwanted high frequency noise.

The efficiency advantage of marine vibrators stems from the ability to control the phase of the emitted signal. This feature can be harnessed to enable novel techniques such as simultaneous sources with very high multiplicity and in creating directional sources that allow for improved crossline interpolation. Scenarios using synthetic-data studies show increased efficiency and/or image quality compared with airguns encoded with random dithering (Halliday et al., 2018).

# Method

The BASS (Broadband Acoustic Seismic Source) vibrator system has been in development for more than a decade. The system has recently been through a series of progressivly more complex trials and is now feature complete.

An operational setup it will consist of multiple vibrators units. Shallow towed vibrators will typically emit signals in the [25-150] Hz band, while more deep towed units will emit low frequrncy energy typically in the [3-25] Hz range.

This will allow us to emit acoustic energy in the full seismic band [~3-150] Hz.

The oveall number of vibrators deployed will be a function of the acoustic signal strength that is needed to image the geophysical target.

A basic towing setup for one single unit is shown in Figure 1.

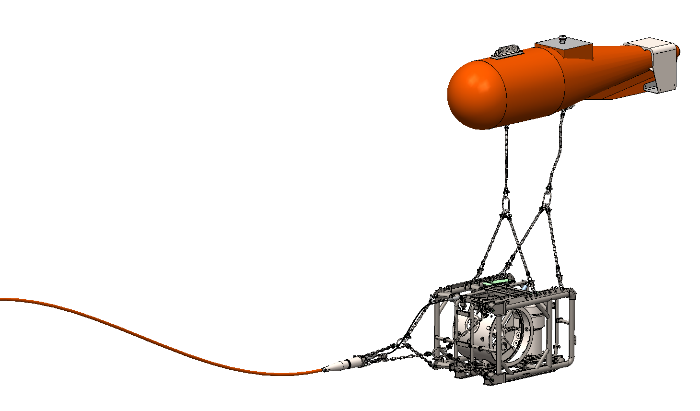


Figure 1. Drawing of the towing-setup where a vibrator is towed below a float.

By having two vibrator units side-by-side we also have the oppertunity to acquire so-called dipole (gradient) source. In consecutive sweeps we can alter the phase such that the units are either in phase (monopole) or 180° out of phase (dipole). The resulting source radiation patterns illustrated in Figure 2 allow for improved crossline interpolation, which translates into gains in either acquisition efficiency or imaging quality.

Finally, we have been testing functionalities and developing software algorithms related to 4D repeatability (Elboth et al. 2022), deblending and residual sweep noise attenuation (Laws et al., 2018a), which we believe will be relevant for a commercial system.

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Figure 2. Crossline source directivity patterns for a monopole (left) and a dipole (right) vibrator source in the [~30-150] Hz range. The numbers on the x-axis denote frequency in Hz, while the colors indicate signal amplitude.

# Examples

Apart from acquiring geophysical data, the various trials also allowed us to test and verify the overall system performance.

We have spent time to finetune and verify the vibrator control algorithms designed to minimize harmonic distortion and accounting for variations in ambient pressure caused by ocean waves/swell. As a result, the vibrator total harmonic distortion is favorable as shown in Figure 3.

We have also been developing and testing an INS tracking aided by USBL based positioning system for the vibrators. Simulations have shown that we need to know the vibrator unit positioning with a few decimeter accuracy in order to comput notional source, e.g. what the vibrator actually emitted during a sweep. The estimation of this notional source is then used in the sweep deconvolution that transforms the vibrator data from a contineous signal to the “normal looking” seismic data that we are familiar with.

We have found that the vibrator emission is stable and repetitive, as illustrated in Figure 4 where measurment data from15 consequtive sweeps are ploted on top of each other.

This kind of stability is important for future 4D compatibility.

We also have developed a purpose-built real-time QC system that accurately monitors the output of the vibrators units.

Finally, we have developed the first iteration of a towing and handling system for the vibrators. One of the main activities going forward will be to engineer and robustify the vibrator deployment, retrieval, and towing systems. This is a non-trivial engineering problem.

**Results**

We also point out that to get a good subsurface image it is not sufficient to just build a marine vibrator. What is needed is a complete system that includes towing and handling, positioning and navigation, control system software and hardware and finally seismic processing and imaging.

Our BASS (Broadband Acoustic Seismic Source) system includes all of these items. As such, it has required a significant engineering effort.

On the results side, we also show the measured and verified acoustic output of the vibrator as illustrated in Figure 5. These numbers show that a single vibrator outputs significant energy. We believe that by combining 3-6 units, low frequency imaging of even deep pre-salt reservoirs should be realistic.

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Figure 3. Top: Spectrogram of a 5 sec [30-150] Hz sweep recorded on accelerometers mounted on the radiator. The lower red line represents the sweep, while the higher order harmonics are visible in green and yellow. Bottom: Showing that the harmonics typically are 40-60 dB down from the primary signal at 0 db.



Figure 4. Left: 15 consecutive [3-25] and [25-150] Hz sweeps plotted on top of each other. The data used here is the computed Notional Source data – based on NFH recordings. Right: A zoom of the waveform showing stability.

Chart, line chart

Description automatically generated

*Figure 5. The confirmed sound level (SL) of one LowBand and one HighBand vibrator units.*

# Conclusions

Depending on the target (reservoir) depth, deploying between 2 and ~6 vibrator units should provide sufficient acoustic energy for seismic imaging. This means that from a geophysical point of view vibrator units can be seen as a one-to-one replacement for an airgun string. Having such a viable alternative to conventional airgun based sources will be a first for the industry.

Accurate phase and amplitude control allow novel geophysical features like the use of a dipole source, that has the potential to offer efficiency and/or quality improvements compared to conventional airgun-based surveys.

On the enviromental side, marine vibrators are believed to be less intrusive than airguns. As such they may allow operations in areas the use of airguns are restricted today.

The development of our vibrator system is still ongoing, and further offshore testing will be required before it is made commercially available. Furthermore, more units need to be produced if we want to have enough acoustic output to image deep pre-salt reservoirs.

# Acknowledgments

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