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Marine Vibrator Source: Modular System with Folded Oscillating Surface

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Summary

There is a desire by the marine geophysical industry for a seismic source with a low environmental footprint. Received sound pressure level (SPL) and sound exposure level (SEL) can restrict how seismic surveys can be conducted in sensitive areas.

To address this desire, we have developed a broadband non-impulsive source based on the concept of modular transducer elements. The source has a controlled output that can emit arbitrary signals, enables flexible source geometries, and can produce ultra-low frequency content that facilitates robust full waveform inversion.

Sea trials and testing indicate that the developed source will meet the challenging output demands and exhibit the necessary robustness to be a viable seismic source for the future. Large scale testing is planned in 2019.

Introduction

There are several ongoing initiatives of seismic source development within the marine seismic industry. Improved source solutions have been presented using both traditional air guns (Gerez et al. 2015) and marine vibrators (Feltham et al. 2017). Lowering the sound pressure level (SPL) and sound exposure level (SEL) are relevant for seismic surveys in environmentally sensitive areas, since these form thresholds for how surveys may operate at various distances from observed marine mammals, marine parks, commercial fisheries, etc. (Duncan et al. 2017).

In comparison to traditional marine air guns which can only generate an impulsive source signal, non-impulsive marine vibrators offer additional signal control options. Some of the possible advantages of marine vibrators are (1) operation at lower SPL value for fixed required SEL, (2) controlled signal output giving opportunities for new and flexible source geometries, (3) potential for ultra-low frequency 1-6 Hz output to benefit full waveform inversion (Rietsch, 1977; Dellinger et al. 2016; Brenders et al. 2018). In order to address these benefits, we are developing a new non-impulsive marine seismic source as an alternative to traditional impulsive marine seismic sources.

The broadband system

Like most marine vibrators, our source generates an acoustic wavefield by actuating a vibrator surface to displace the surrounding water. Our basic vibrator element consists of two parallel plates actuated toward and away from each other. Arranged in proximity to each other, a multitude of these vibrator elements forms a modular projector system (Armstrong, 2015). Because the vibrator's output pressure is proportional to the plate acceleration, the plate motion needs to increase at lower frequencies as $1/f^2$ in order to keep the output at a constant level. Hence, the lowest frequencies of the seismic spectrum are the most challenging to produce. This relationship holds for the seismic frequencies at which the vibrator is small compared to the dominant wavelength, and the radiated power depends only on the displaced volume (Kinsler et al. 2000).

In order to achieve a desired pressure output over the entire frequency band, we divided our source into low frequency (LF) and high frequency (HF) modules. The LF module is pictured in Figure 1.

Figure 1 *Source low frequency module.*

The LF module is specially designed to drive a large radiating area at small displacement, whereas most other solutions drive small radiating areas at large displacement (Roy et al. 2018, Tenghamn and Long 2006). This is achieved by building one folded surface covering small cylindrical connected cavities, shown in Figure 1. Working with small displacements means that the source sees lower vibration stresses, which will directly translate into a longer service life and lower acoustic distortion. Additionally, the small displacements can be accommodated by a bending metal interface, rather than rolling elastomeric or sliding seal interfaces required by large-displacement vibrators. The LF module is built to achieve full power output down to 75 m operating depth, allowing it to exploit the surface ghost's negative impact on low frequencies. The source system also contains a control system capable of transmitting arbitrary coherent signals, on-board motor drive amplifiers, active pressure compensation, and comprehensive source monitoring.

System testing

The basic system design was developed over a number of years, maturing by 2016. Recent efforts have been focused on proving operational reliability and scaling up from single module calibrations to multi-module full band exercises. Both the LF and HF modules have undergone multiple sea trials (Figure 2 and Figure 3) at full depth and full power, and the HF module was demonstrated at the Seneca Lake test facility in December 2017. The LF module has undergone extensive in-laboratory tank testing, including a successful 1,000 hour lifetime test in spring 2017. The system has matured enough to justify a preproduction build of an additional LF module and HF modules in 2018/2019 to support planned field trials in 2019.

***Figure 2** HF module calibrations at Seneca Lake test facility.*

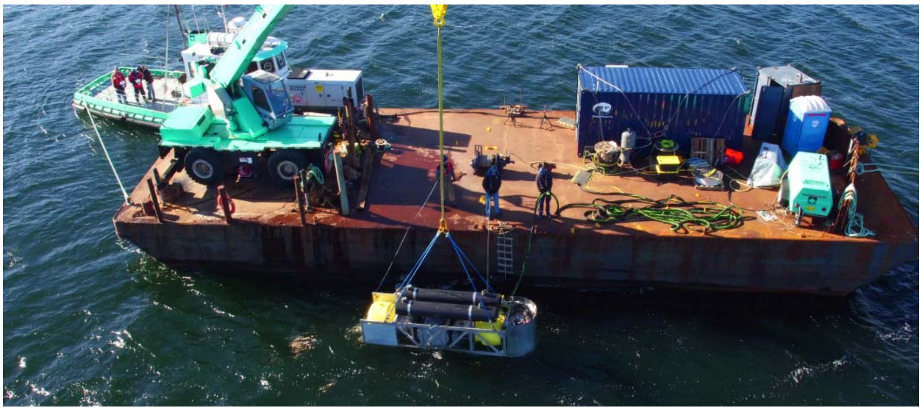

***Figure 3** LF module sea trials in Bedford Basin, Canada.*

Acoustic system performance

Both amplitude and phase are controllable and repeatable, allowing arbitrary signal generation. Source response curves are presented in Figure 4, and an example of both modules simultaneously running a 5s sweep is presented in Figure 5. A single LF module is capable of covering the 1-10Hz band with similar performance both shallow and deep. The HF module is more compact with higher peak power, but cannot achieve as much low frequency power. The modular nature of the source allows any number of LF module and HF module to be combined to produce the desired source signature.

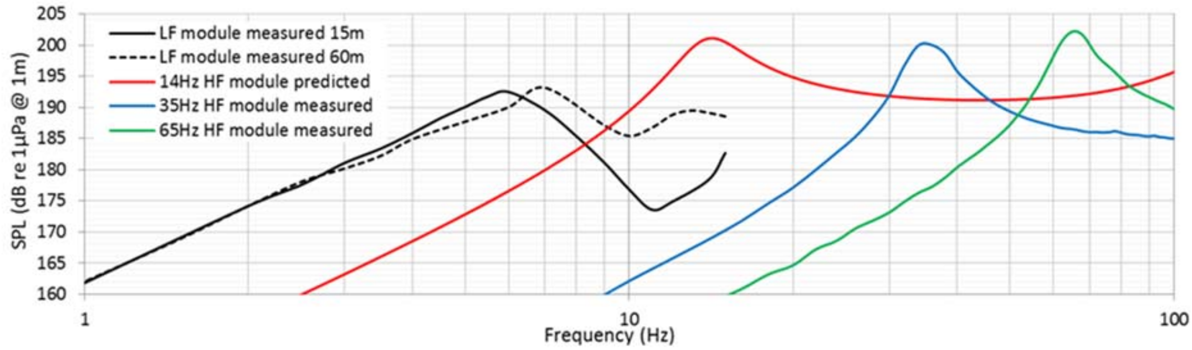

Figure 4 *Source response of the modules. LF module tested at 15m and 60m depths, and all HF modules at 15m. The HF module resonant frequency is tuned: test data for 35Hz and 65Hz tunings is presented alongside predicted output for the 14Hz tuned units currently in production.*

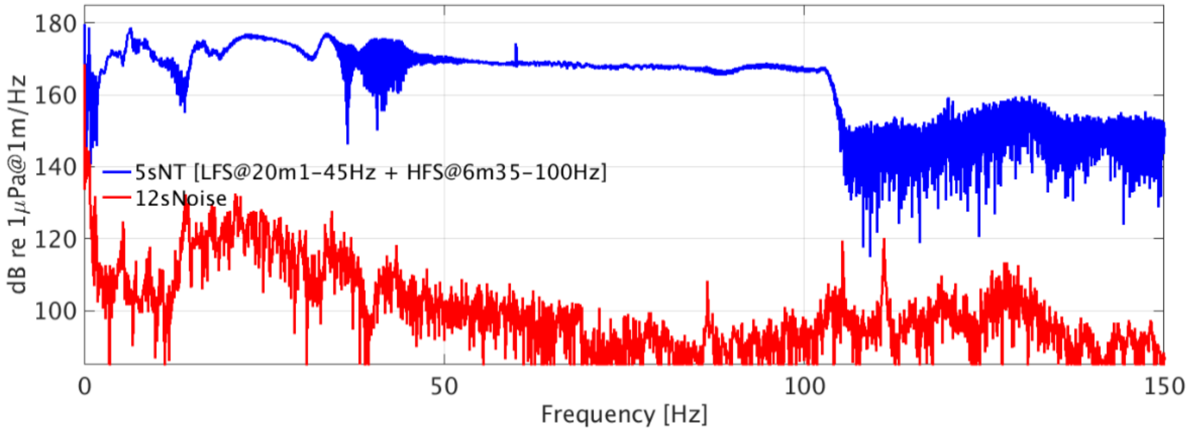

Figure 5 *Measured performance of one LF module and one HF module run simultaneously across a 5s sweep.*

The source features controlled output level (SPL, SEL) and frequency content. The modular nature of the system makes it possible to compose an output tailored specifically for the geology of interest while taking environmental impact into account. In addition, it is an inherently low distortion system with little energy loss outside the active band as shown in Figure 5. Active distortion reduction algorithms such as iterative learning control (ILC) are used to suppress in-band and out-of-band distortion as shown in Figure 6.

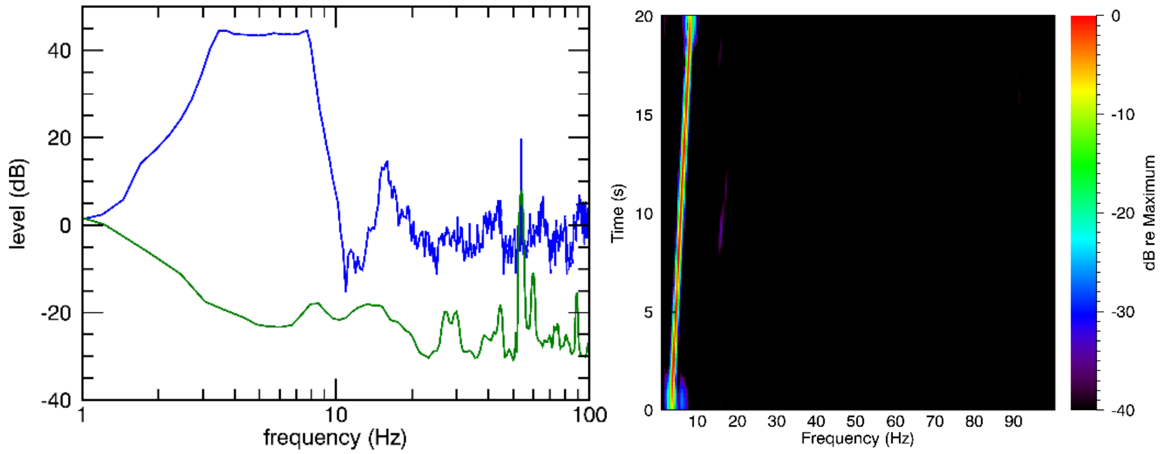

***Figure** 6 Active distortion reduction applied to a 20s 3-8Hz sweep displayed as full spectrum (Left) with the pulse (blue) compared to the background noise (green) and as a sonogram (Right).*

Conclusions

We have developed and tested a unique, non-impulsive vibratory marine seismic source that uses small displacements of large surfaces to reliably produce high output across the seismic band. With high amplitude and phase control, this coherent system is capable of arbitrary signal generation. The system outputs a minimum of energy outside the operating band, and the modular nature of the system makes it possible to compose a tailored output taking environmental impact into account. The source has undergone over 1,000 hours of lifetime testing, and performed consistently across multiple sea trials in 2017 and 2018. Based on these successful results, we plan to build additional source modules to support a larger scale testing in 2019.

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