A very low frequency source operated close to the surface.

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This paper was prepared for presentation during the 18th International Congress of the Brazilian Geophysical Society held in Rio de Janeiro, Brazil, 16-19 October 2023.

Introduction

There has been an increasing interest in the industry for a very low frequency (VLF) seismic sources. Adding low frequencies could add octaves in bandwidth. It is well known that higher frequency waves will be attenuated more rapidly than lower frequency waves, and consequently, lower frequency waves can be transmitted over longer distances through water and geological structures. In addition, the lowest frequency range can be important for deriving the elastic properties of the subsurface by seismic full wave field inversion (FWI). Accordingly, there has been a need for powerful low frequency marine sound sources operating in the frequency band of 1 to 5 Hz.

There are several concepts that have been presented over the years. Both impulsive sources and marine vibrators. There are several problems with existing concepts like repeatability, complexity, and the cost to operate. Dellinger et al. (2016) describe an ultralow-frequency source prototype. Maier et al (2015) propose a dipole source for low frequency seismic acquisition.

This paper describes a VLF seismic vibrator designed to be efficient and without the need of being towed deep to avoid the ghost notch. Godin (2006) showed the effect of low frequency sound close to the water-air interface. The source can be operated from a small vessel with a handling system that does not require a complex depth control system. Working with a variable spring system make the source efficient and controllable. It offers better resolution, recovery of signals from a greater distance, and improves full waveform inversion.

Method and Theory

The figure below shows the installation of the low frequency source on a catamaran vessel. Having a dipole source will normally create the problem of a fixed reference point. Having for example a dipole source hanging freely in the water column would be problematic since the up and down going movement needs to be fixed to some structure. In this paper we describe having a surface vessel rigidly attached to the source. We can for example have a catamaran with a structure that can be moved up and down into the water for deployment and retrieval. The source is then attached to the structure and can be lowered to a predetermined depth of 1-5 m. The source itself is then attached to the structure and can be made very simple due to this arrangement. The source consists basically of a plate with a certain surface area. The plate is then moved up and down with the help of linear motors to generate the force needed. The plate's amplitude will be in the order of +/- 0.1 m.

If the source had no resonance in the frequency band of interest the efficiency would be very low. In this case we must use a lot of energy into the source to generate a small amount of energy into the water column. To understand the importance of resonances for an acoustic source which have a size that is much smaller than the wavelength generated we must look at the impedance for a source.

In analysis of the energy transfer of a marine vibrator, the system may be approximated as a baffled piston. For low frequencies, when x = 2ka (*k* = wave number, a = radius of a piston) is much smaller than 1, the real and imaginary part of the total impedance expression may be approximated with:

$$R(x) \rightarrow \frac{1}{2}(ka)^2 \qquad X(x) \rightarrow \frac{8ka}{3\pi}$$

It follows that for low frequencies *R* will be a small number compared to *X*, which suggests a very low efficiency signal generation. However, by introducing a resonance the low frequency acoustic energy may be generated more efficiently. At resonance the imaginary (reactive) part of the impedance is cancelled or significantly reduced, and the acoustic source can efficiently transmit acoustic energy into the water.

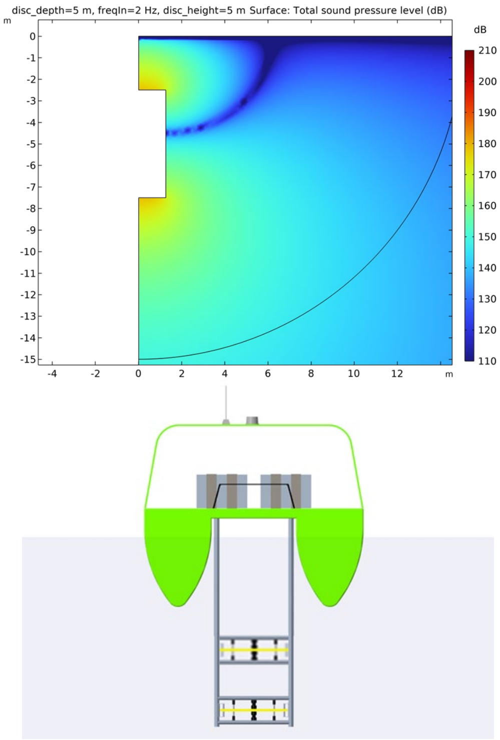

Figure 1 *On top a finite element simulation is shown of a dipole source 2 m from the surface. The model is a ¼ symmetry model, hemisphere of water with an infinite water domain. The size of the source shown is 2.5 x 2 m and 5 m in the vertical direction. Below we have an artist view of how the source could be installed on a small vessel. Two vibrating plates is lowered down to a desired depth (for example 5 m) and the plates is set in an oscillated motion.*

By introducing adjustable spring elements to the sound emitting surface, we can improve the efficiency of the sound wave generated. The sound emitting surface will have a resonance which depends on the equivalent water mass acting on the surface, which is the amount of water oscillating with the vibrating sound emitting surfaces and the weight of the plate itself, and the stiffness of the spring elements.

Having a source operating from 1-5 Hz means that we can either select the resonance to be any of these frequencies. Another possibility would be to have a variable spring constant in the spring elements. In the case we run a sweep from 1-5 Hz the spring constant can be adjusted accordingly to create a resonance from 1-5 Hz along the sweep generated. In this case the efficiency of the source would improve considerably.

The source plate would be attached to the structure with for example linear bearings and the linear motors and spring elements would be fixed to the structure with the moving part fixed to the plate.

Conclusions

The paper describes a new very low frequency source that is easy to deploy and operate from a small vessel. The source deployed at a water depth of 5 m will give a SPL of more than 190 dB rel. 1 micro-Pa in the frequency range from 2 to 5 Hz. At 1 Hz the source produce about 188 dB. This show how a less complex source can be used to create the low frequencies needed for FWI.

References

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