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High frequency ghost cavitation – a comparison of two seismic air-gun arrays using numerical modelling

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Abstract

Ghost cavitation is probably the mechanism behind the majority of high frequencies (above 5 kHz) generated by seismic air-gun arrays. Such high frequencies are less important in seismic reflection imaging. High frequency sound might impact marine fauna and particularly marine mammals. In this paper the array signatures and high frequency ghost cavitation signals for two different arrays are simulated using numerical modelling. It is observed that one array has slightly more (20%) energy within the seismic frequency band (1-100 Hz) but emits significantly more energy (150%) for frequencies above 5 kHz.

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Keywords: air-gun array; high frequency generation; ghost cavitation; numerical simulation

1. Introduction

Underwater ocean noise generated by human activities has increased over the last century. Seismic surveys besides shipping, military activities, and pile driving, are one of the major man-made underwater acoustic noise sources [1]. Cetaceans use acoustic waves for several essential purposes including finding prey, mating, social interaction, and avoiding predators [2]. There are widespread and increasing concerns regarding the adverse impacts of anthropogenic underwater acoustics on marine mammals which include physical and physiological effects,

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acoustic masking, behavioral reactions, and chronic stress effects [3-5]. There are evidences of both short–and long–term behavioral changes as a result of elevated background noise. Measurements indicate that right whale calls have shifted to higher frequencies within around three decades [6] which is related to the increased noise in the frequency band of their calls. Other measurements have shown a correlation between the amount of stress hormones in whales and underwater noise [7]. Behavioral disturbances were observed in different marine mammals subjected to the noise from seismic air-guns, and it was more pronounced in smaller species [8]. During and after the end of exposure to naval sonar signal, the feeding behavior of humpback whales was interrupted [9]. As a result of operating seismic survey there was observed both increase and decrease in fish catch rates [10]. The increase in catch rate is attributed to the elevated swimming activities that can be an indicator of increase stress due to seismic shooting which in the long run may result in reduce in catch rate.

To extract the information about geological structure beneath the seabed, marine seismic reflection profiling is used. In marine seismic surveys an active source is used to generate acoustic waves that propagate into the Earth. Acoustics waves reflected at interfaces between layers with different seismic velocities are recorded by hydrophones embedded within long streamers towed behind a seismic vessel or by geophones located at the seabed. Air-gun arrays, marine vibrators and water-guns are the main marine seismic sources [11-12]. Among them, however, air-gun arrays are by far the most common and efficient seismic sources [13]. Air-guns generate impulsive acoustic waves by discharging highly pressurized air into the surrounding water [14]. An air-gun array contains several (typically 12 to 48) individual air-guns. The purpose of using air-gun arrays, instead of a single air-gun, is to increase the source strength, to focus the acoustic pressure signal in the vertical direction, and to damp unwanted bubble oscillations (that occur after the primary acoustic signal) to improve the source signature [15].

Air-gun arrays generate broad-band acoustic waves from a few Hz up to tens of kHz [16-17]. Only low frequencies (< ~100 Hz) are useful for deep seismic imaging since they penetrate deeper into the Earth. Even though high frequencies (>1000 Hz) can be used to detect gas leakage from a CO_2 storage site or an oil and gas production field [18], such higher frequencies are mostly considered as waste energies and are filtered out prior to the processing step [19]. Considering hearing curves of marine mammals it can be inferred that the emitted high frequencies from air-gun arrays may have negative impact on several cetacean species, as for instance toothed whales [17,20].

There are several underlying mechanisms for high frequency generation related to air-gun arrays. To reduce the high frequencies attributed to steep rise time of pressure waves of each individual air-gun a new air-gun has been designed and tested [21,22]. Interaction between reflected ghost wave and air-gun bubble also generates frequencies between 400 and 600 Hz [23,24]. In air-gun arrays, another underlying mechanism for generating frequencies up to tens of kHz is called ghost cavitation [17]. Recording the far-field signals from marine seismic air-gun arrays using broad band hydrophones it was observed that full air-gun arrays signals contain high frequency signal which appears few milliseconds after the ghost signal [25,26]. Reflected ghost signals from individual air-guns in the array "add up" and drop the absolute hydrostatic pressure to zero in some locations for a short time. In such regions cavities can grow and their subsequent collapse generates intense noise. Using numerical modelling ghost cavitation hypothesis was further validated [27]. Numerical modelling results indicate that ghost cavitation signal contains low frequencies in addition to the high frequencies [28].

In this paper the array signature and high frequency ghost cavitation signal from two air-gun array configurations are numerically simulated. The array configurations are compared with regard to their useful seismic frequency band and the undesired waste high frequencies generated by ghost cavitation phenomena. It is shown that selection and arrangement of individual air-guns in the array can be optimized to reduce the waste high frequencies without compromising the low frequencies that benefits seismic imaging.

Nomenclature

R	time dependent radius of cavity (m)
t	time (s)
P	external pressure (Pa)
P_i	pressure inside the cavity (Pa)