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The pressure field generated by a seismic airgun

K.L. de Graaf*, P.A. Brandner, I. Penesis

Australian Maritime College, University of Tasmania, Tasmania 7250, Australia

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ABSTRACT

A model-scale seismic airgun is used to investigate the behaviour and pressure field of the bubble generated at different standoffs from a steel plate and a free surface in an open top tank. The airgun is fired at 50 and 100 bar initial pressures and the field pressure, wall pressure and wall acceleration are recorded. Wavelet and Fast Fourier Transforms are used to analyse the bubble frequency. The reduction of pressure with distance from both the initial shock and first bubble collapse are presented. The hydrodynamic component of the pressure signal generated by the bubble collapses is also discussed. The trend of the bubble period for different standoffs from the free surface is compared with other data in the literature and found to be similar. The acceleration and displacement of the steel plate are presented for varying bubble standoffs, and as the plate moves in phase with the bubble, little pressure is felt from the collapse pulses. This information provides basic understanding of the dynamics of an airgun bubble when considering their application as a method of shock testing naval ships.

1. Introduction

Seismic airguns are primarily used as an impulsive pressure source in marine exploration for surveys of the ocean floor subsurface. Multiple airguns are fired simultaneously in an array to produce the single shock required for reflection and refraction surveys. Geophysicists require an understanding of the bubble dynamics and the emitted pressure signal of a single airgun in order to better understand the interactions between several airguns and the ultimate useable shock signature. Much of the research is focused on synchronising the array to produce one strong shock and minimise the following pressure pulses due to bubble oscillations.

Experimental airgun investigations are generally carried out using full-scale airguns. Exceptions to this include studies undertaken with a small commercial BOLT 600B airgun (firing volume 26 cm^3), in which holographic and high-speed images and signature measurements were acquired [1,2]. Further investigations with this airgun focused on the effects of varying water temperature and viscosity on the emitted signature [3,4]. High-speed camera images of the bubble from a 163 cm^3 airgun were presented by Bungenstock [5]. Some frequency spectra of the pressure signal were also given.

Full-scale measurements have been analysed for use in developing numerical models of the generated pressure signature. These include Ziolkowski [6], who found that Gilmore's equation with a polytropic constant of 1.13 gave good results for the first period of oscillation. Johnston [7] compared the performance of airguns fired at 138 and 414 bar. Laws et al. [8] compared three methods of prediction of the pressure field generated by an airgun array through experimental testing. Vaage et al. [9] analysed measurements of airgun array firings to develop relationships between varying parameters. de Graaf et al. [10,11] developed a numerical model of the growth and pressure field of an airgun bubble which compared well with full-scale airgun trial results.

Recently, there has been an interest in the use of seismic airguns for shock testing naval vessels. The Australian Government Defence Science and Technology Organisation (DSTO) have completed two trials with full-scale commercial SERCEL airguns in which field pressures and the response of a small scale hull to varying shocks were measured [12,13].

Research done on bubble behaviour near boundaries is often done in the field of cavitation in which spark and laser-generated bubbles are used to investigate the dynamics, period and radiated pressure from oscillating bubbles, for example [14–18] ([18] are free field results only). Recent experiments conducted with underwater explosions focusing on bubble dynamics near a boundary include Klaseboer et al. [19] and Hung and Hwangfu [20].

This paper presents the results from a series of experiments conducted at the Australian Maritime College (AMC) with a purpose built laboratory scale airgun, modelled on the airguns used by DSTO. These experiments study the field and wall pressures produced by the airgun when fired at two different pressures at

* Corresponding author. Tel.: +61 6324 9723; fax: +61 6324 9592.
E-mail address: kdegraaf@amc.edu.au (K.L. de Graaf).

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0894-1777/

varying standoffs from a steel wall and depths from a free surface in an open top tank.

2. Experimental setup

2.1. Laboratory scale airgun

A laboratory scale airgun has been designed based on a typical four port airgun. The airgun has a firing volume of 14.5 cm^3 and can be pressurised up to 100 bar from a standard dive bottle. Major external dimensions of the airgun are given in Fig. 1. The cylindrical airgun body has four 20 mm wide by 8 mm high ports through which the air is released, and is fitted to a pipe of equal outside diameter, as shown in Fig. 2.

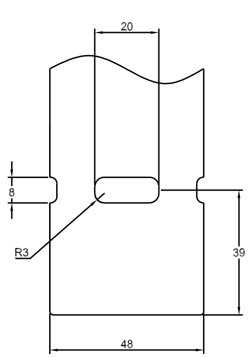
The basic operation of an airgun is similar across the commercial range and uses a pressure differential to fire a shuttle which rapidly releases a fixed volume of compressed air to form a bubble. Due to the small size of this airgun and the limits in valve sizes and drilling diameters, a central control rod creates the air passages required to facilitate charging and firing the airgun.

Initially, the control rod is positioned to allow the firing chamber to be charged with compressed air (Fig. 2a). The shuttle is held in place by the pressure difference between the two ends of the shuttle as the upper flange of the shuttle is slightly larger than the lower flange. The control rod is then moved up, exposing the back of the upper flange to the firing pressure (Fig. 2b) and resulting in a net force acting on the lower flange such that the shuttle opens, discharging the compressed air through the four ports (Fig. 2c). The control rod moves back into the body to prevent excess additional air holding the shuttle open. A spring returns the shuttle to its closed position and the control rod is then reset.

2.2. Testing tank and equipment

Experiments were carried out in the AMC Cavitation Research Laboratory. The airgun was suspended vertically in the centre of a 1.728 m^3 open top water tank with dimensions of 1.2 m × 1.2 m × 1.2 m. The tank is constructed with one 16 mm stainless steel plate side and the remaining three sides and base of 50 mm clear acrylic. A Brüel & Kjær (B&K) Type 8103 hydrophone and B&K 2692 signal conditioning amplifier were used to measure the bubble pressure pulse in the field at varying distances from the airgun. A B&K Type 4507 B004 Deltatron accelerometer and PCB 112A21 pressure transducer, both of which were used with a PCB Piezotronics 482C signal conditioner, were located on the steel wall to measure the wall pressure and acceleration. The pressure transducer was located at the centre of the plate with the accelerometer adjacent. The airgun was fired using a solenoid

(a) Image of model-scale airgun



(b) Major external dimensions of the model-scale airgun

Fig. 1. Model-scale airgun.

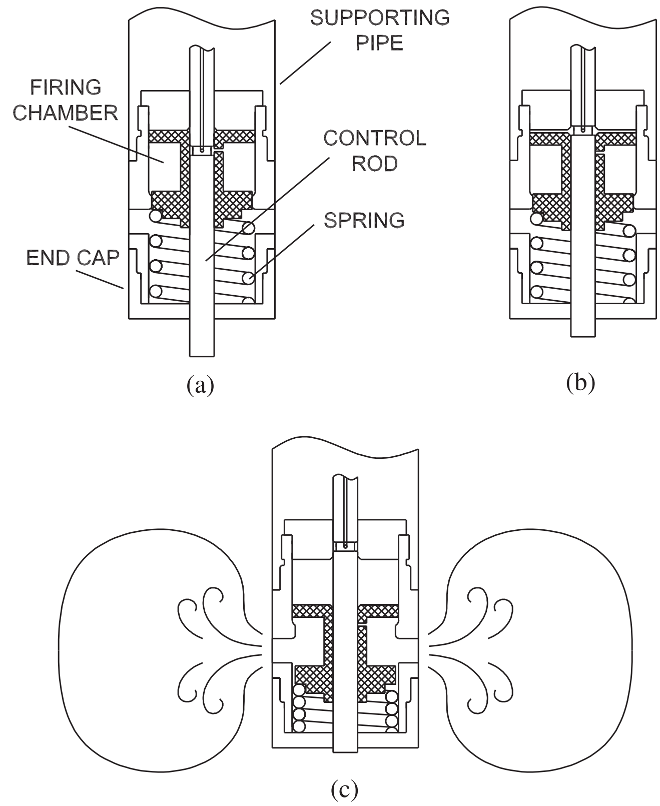


Fig. 2. Illustration of the model airgun firing in three stages: (a) pressurised chamber under equilibrium; (b) equalisation of pressure across upper flange to fire shuttle and (c) release of air through ports to form bubble.

(GTUW 070 T43 A01) to move the control rod upwards. A trigger pulse on firing was directed via a variable delay (Thurlby Thandar Instruments TGP110) and used to initialise data recording from the pressure transducers and accelerometer. Data from the two pressure transducers and the accelerometer were recorded at 100 kHz using a National Instruments (NI) PCI-4472 simultaneous sample and hold acquisition card. In addition to the dynamic data, the charged airgun pressure and ambient pressure were measured and recorded using a Wika S-10 pressure transmitter on the air supply and a Vaisala PTB 210C4C2M barometer, respectively, via a NI PCI-6289 acquisition card. Bubble radii were derived from high-speed photography recordings acquired at 3 kHz using a La Vision High-Speed Star 5 camera. A diagram of the experimental setup is shown in Fig. 3 and a schematic of the data acquisition equipment in Fig. 4.

The first set of experiments focused on determining the pressure response at varying distances from the airgun. Results were obtained for 50 and 100 bar initial airgun pressures for the cases where the hydrophone was traversed away from the airgun (at the same depth as the bubble) and where the airgun was progressively moved toward the steel plate (with the hydrophone position fixed). The vertical changes in the pressure field were tested by lowering and raising the hydrophone at one horizontal offset with respect to the fixed depth airgun. To assess the directivity of the airgun due to the arrangement of the four ports (symmetric about four axes), the airgun was rotated in 15 degree increments through a total of 45 degrees. Interaction of the bubble with the free surface was studied by reducing the water level. The airgun and hydrophone remained in the same position relative to the tank to enable photography and pressure transducer results to be obtained at the same depth as the bubble.

An image taken at the time the bubble reaches its first maximum radius is shown in Fig. 5. This figure shows the four distinct