Experimental Thermal and Fluid Science 55 (2014) 228–238

Contents lists available at ScienceDirect

Experimental Thermal and Fluid Science

journal homepage: www.elsevier.com/locate/etfs

Bubble dynamics of a seismic airgun

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

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

ARTICLE INFO

Article history:
Available online 25 February 2014

Keywords:
Seismic airgun
Bubble dynamics
Rayleigh–Taylor Instability

ABSTRACT

The dynamics of the bubble generated by a four port model-scale seismic airgun in an open top tank are investigated. The airgun is fired at 50 and 100 bar and bubble images are captured with low- and high-speed photography. Forward- and back-lit photography allows close observation of the phenomena at the gas–water interface, and measurement of the radial growth, respectively. The development of the Rayleigh–Taylor Instability on the bubble's surface is identified. Field pressure measurements, synchronised in time with the radial bubble growth, are presented, and features of the emitted pressure signature are associated with the physical bubble dynamics. The experimental data is compared with an analytical prediction based on the Gilmore equation and good agreement is found for bubble radius, bubble period and the pressure pulse emitted at bubble collapse. The initial shock wave and first maximum velocity were over-predicted by this method.

1. Introduction

Seismic airguns have been developed for the generation of seismic pulses for ocean seabed geophysical exploration. Research on airguns has primarily been driven by the development of these geological surveying techniques and has focused on quantifying the initial shock wave emitted and using the interaction of multiple airguns to minimise the following bubble pulses. This primarily involves pressure measurements and development of numerical and empirical methods.

Bubble dynamic models such as the Gilmore equation and Rayleigh equation (or Rayleigh–Plesset equation, if surface tension and viscosity are included) are commonly used as the underlying basis for models of seismic airgun bubbles despite their deviation from a strictly spherical form. The dynamics and behaviour of the bubble produced by an airgun are not particularly well understood as obtaining high-speed photography of full-scale airguns is difficult when considering water quality and domain size.

The attributes of an airgun are also suitable for use in shock testing ships. Several navies are developing methods for this application and the Australian Government Defence Science and Technology Organisation (DSTO) have completed two trials with commercial SERCEL airguns. These trials measured the pressure field produced by the airgun and its effect on a scale model hull section [1,2]. A frame from high-speed video footage (provided by SERCEL) of the bubble produced by a full-scale airgun is shown in Fig. 1.

Studies on the bubble formed by an airgun have been presented by Bungenstock [3] and Langhammer and Landrø [4]. Bungenstock presents high-speed photography of the airgun bubble and discusses bubble damping with a view to suppression of the bubble that follows the initial shock (which is desirable in geophysical applications). The airgun studied by Bungenstock had a volume of 163 cm^3 and was fired at 150 bar. Langhammer and Landrø studied a 26 cm^3 BOLT 600B airgun fired at 100 bar, also using high-speed photography. The presence of water droplets or fog within the bubble was suggested as an explanation of the differences between modelled and measured signatures from airguns. Predictions of the bubble produced by a seismic airgun have been made by Schulze-Gattermann [5], Ziolkowski [6,7], Johnston [8], Laws et al. [9], Li et al. [10] and de Graaf et al. [11]; however, uncertainties in the damping mechanisms still exist.

Unlike classical bubble work, where an initially spherical bubble is generated, the initial dynamics of a seismic airgun bubble are controlled by the impulsive release of gas through ports. Very little work has been published on impulsive, transient gas jets in liquids. Past work is focused on continuous jets and the subsequent dynamics and instabilities at varying flow rates, for example Weiland and Vlachos [12], Dai et al. [13] and Chawla [14].

A laboratory scale airgun and test facility, developed at the Australian Maritime College (AMC), has been used with low- and high-speed photography to study the dynamics of the air bubble generated. The photographs captured are of higher resolution than those previously presented in literature and allow the bubble physics to be explained in greater detail. Insight is given into the dynamics of a transient impulsive gas jet in water. Bubble growth measurements are presented with simultaneous field pressure

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

http://dx.doi.org/10.1016/j.expthermflusci.2014.02.018
0894-1777/

Fig. 1. Single frame of video footage provided by SERCEL of GGun150 fired at 138 bar (2000 psi).

measurements, and are compared with the analytical model developed in de Graaf et al. [11].

2. Experimental setup

2.1. Laboratory scale airgun

A laboratory scale airgun has been designed based on a typical four port airgun. It has a firing volume of 14.5 cm^3 and can be pressurized up to 100 bar from a standard dive bottle. Major external dimensions of the airgun are shown in Fig. 2. 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. 3.

The operation of the model-scale airgun is based on the full-scale varieties and uses a pressure differential across two ends of a flanged shuttle to rapidly release a volume of compressed air, which forms the bubble. When the firing chamber is charged, the shuttle is held in place by the pressure difference acting on the slightly larger upper flange (Fig. 3a). A central control rod drilled with small air passages is then moved upwards to expose the back of the upper flange to the firing pressure (Fig. 3b). This results in the net force of the compressed air acting on the lower flange, immediately opening the shuttle and releasing the air through the four ports (Fig. 3c). Once the air is exhausted, a spring returns the shuttle to its closed position and the control rod is then reset.

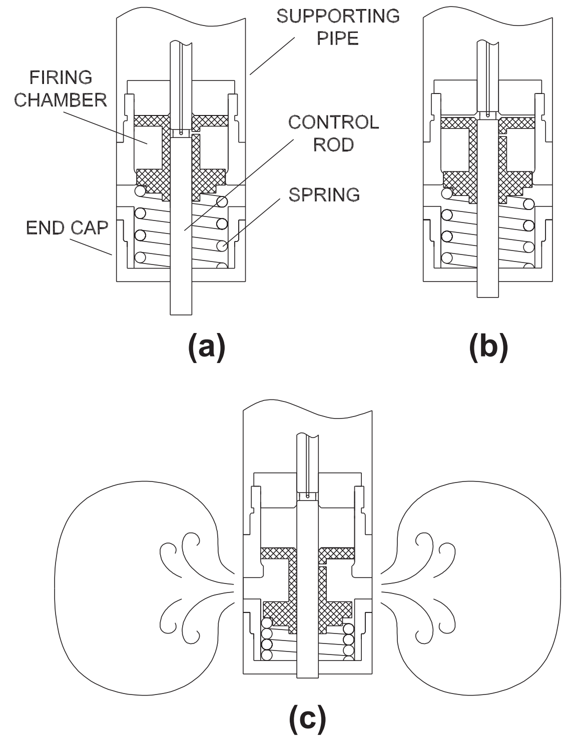

Fig. 3. Illustration of the model-scale airgun firing in three stages: (a) pressurised chamber under equilibrium; (b) equalisation of pressure across upper flange to fire shuttle and (c) release of air through ports to form bubble.

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. The arrangement of the tank is shown in Fig. 4. High-speed photography was taken using a LaVision High-Speed Star 5 camera with a Nikon Nikkor 55 mm F-1.4 lens

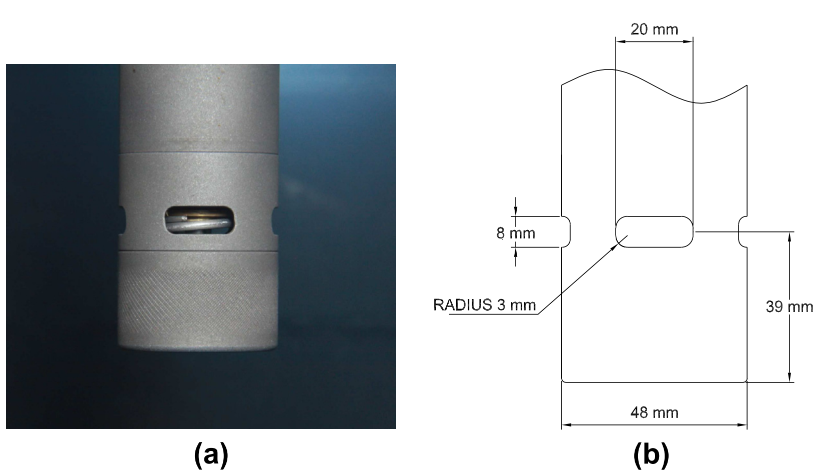

Fig. 2. Model-scale airgun. (a) Image of model-scale airgun and (b) major external dimensions of the modelscale airgun.