Available online at www.sciencedirect.com

ScienceDirect

Defence Technology 10 (2014) 245–250

www.elsevier.com/locate/dt

Shock tube design for high intensity blast waves for laboratory testing of armor and combat materiel

Elijah COURTNEY [a], Amy COURTNEY [b,*], Michael COURTNEY [a]

[a] BTG Research, P.O. Box 62541, Colorado Springs, CO 80962, USA
[b] Exponent, Inc., 3440 Market Street, Philadelphia, PA 19104, USA

Received 10 January 2014; revised 27 March 2014; accepted 15 April 2014
Available online 24 April 2014

Abstract

Shock tubes create simulated blast waves which can be directed and measured to study blast wave effects under laboratory conditions. It is desirable to increase available peak pressure from ~1 MPa to ~5 MPa to simulate closer blast sources and facilitate development and testing of personal and vehicle armors. Three methods are experimentally investigated to increase peak simulated blast pressure produced by an oxy-acetylene driven shock tube while maintaining suitability for laboratory studies. The first method is the addition of a Shchelkin spiral priming section which supports a deflagration to detonation transition. This approach increases the average peak pressure from 1.17 MPa to 5.33 MPa while maintaining a relevant pressure-time curve (near Friedlander waveform). The second method is a bottleneck between the driving and driven sections. Coupling a 79 mm diameter driving section to a 53 mm driven section increases the peak pressure from 1.17 MPa to 2.25 MPa. A 103 mm driving section is used to increase peak pressure to 2.64 MPa. The third method, adding solid fuel to the driving section with the oxy-acetylene, results in a peak pressure increasing to 1.70 MPa.

Keywords: Shock tube; Blast; Blast injury; Armor

1. Introduction

The use of improvised explosive devices (IEDs) has greatly increased in recent military conflicts, and as a direct result, more soldiers are also being exposed to explosions [1,2]. It has been shown that the blast wave from an explosion can cause injuries apart from projectiles or impacts; these have been called primary blast injuries. The recent increase in injury to personnel and blast-induced damage to materiel has motivated laboratory scale experiments on the effects of blast waves [3–5]. Goals of such experiments include the improvement of armor and the treatment of blast-induced injuries. The shock tube is an instrument that is used to simulate a blast wave so that the simulated blast wave can be directed and measured more easily, and so experiments can be conducted in laboratory conditions [5,6].

Shock tubes have been used to study high speed aerodynamics and shock wave characteristics as well as the response of material to blast loading for over a century [7]. More recently, the value of using shock tubes to understand and prevent blast-related injuries has been demonstrated. Most shock tube designs are one of two main categories based on how the simulated blast wave is created: compression-driven [8,9] or blast-driven [10,11]. However, each of these has some limitations. Design details and dimensions of compression driven shock tubes vary, but the basic principle is that pressure builds in a driving section separated from the longer

---

[*] Corresponding author. Tel.: +1 225 614 1523.

E-mail addresses: acourtney@exponent.com (A. COURTNEY), michael_courtney@alum.mit.edu (M. COURTNEY).

Peer review under responsibility of China Ordnance Society

Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.dt.2014.04.003

driven section by a thin barrier. When the barrier ruptures due to overpressure in the driving section or a mechanical perturbation, the overpressure propagates along the driven section. As the overpressure propagates, the gas dynamics cause a shock wave to form at the leading edge, followed by a decay in the pressure profile that somewhat approximates a blast wave. Compression-driven shock tube designs often produce significant shot-to-shot variations in peak pressure, as well as pressure wave durations that are longer than those of realistic threats such as mines, hand grenades, and IEDs. Often, they do not approximate the Friedlander waveform of free field blast waves [12]. Furthermore, the expansion of the compressed gases results in a jet of expanding gases that transfers additional momentum to the test object.

Blast-driven shock tubes are often relatively simple tubes closed at one end and open at the other. A given quantity of high explosives is located near the closed end and detonated. The blast wave is directed out of the open end by the tube, producing more realistic blast profiles. The detracting feature of blast-driven shock tubes is that their operation requires expensive facilities, liability, and personnel overhead for storing and using high explosives [12].

Previous work showed that a modular, oxy-acetylene based shock tube produced realistic blast waves with peak pressures up to about 1.17 MPa [12]. However, in some situations it may be desirable to increase the peak pressure to as much as 5 MPa to simulate closer proximity to a blast source and assist the development and testing of personal and vehicle armors. Higher blast pressures are also desirable for testing damage thresholds of equipment. A 5 MPa reflected pressure (for the sake of comparison, this paper discusses reflected pressures, that is, pressures determined with the pressure transducer having its flat surface directly facing the blast source) corresponds approximately to a blast produced by a hand grenade (∼0.23 kg charge weight) at a standoff distance of 0.4 m or a 155 mm high explosive (∼10.8 kg charge weight) at 2 m [10].

The present study experimentally investigated three approaches to increase the peak pressure of the simulated blast wave produced by a laboratory scale oxy-acetylene based shock tube. The first method employs the addition of a Shchelkin spiral priming section which supports a deflagration to detonation transition. The second method uses a bottleneck between the driving and driven sections to increase pressure by increasing the ratio between volume of fuel and cross-sectional area of the driven section. The third method adds solid fuel to the driving section with the oxy-acetylene with the goal of increasing the heat and pressure of the blast wave inside the driven section.

2. Materials and methods

In all three designs, a single layer of food-grade plastic film (low density polyethylene) was placed over the open end to contain the mixture before filling the driving section with the fuel-oxygen mixture, and a small ventilation tube was placed parallel to the driving section to allow ambient air to escape during filling. Two layers of Teflon tape were applied to the threads of the driving section before and after placement of the plastic film barrier to prevent the threads from cutting the film prior to ignition. Both driven and driving sections were commercially available steel pipe, and the sections were coupled by a steel flange. For the bottleneck and solid fuel designs, the driving section was sealed with a steel end cap, into which a hole was drilled for ignition access, and the driving section was filled with a stoichiometric mixture of oxygen and acetylene. (This procedure produced 2–6% shot-to-shot variations in earlier work [12] and 3–9% variations here. This level of repeatability is sufficient for most applications.) Combustion products of this mixture were carbon dioxide and water vapor. The ignition source, an electric match, was placed in the ignition access, which was then sealed with putty. The driving section was then threaded into the flange and the leads to the ignition source were attached to a remote 9V DC source [12].

2.1. Shchelkin spiral priming section

A Shchelkin spiral was incorporated into a priming section, which was placed behind the driving section (Fig. 1A). The Shchelkin spiral is hypothesized to work by increasing the turbulent flow of the deflagration wave, thus increasing the chemical reaction rate and wave speed [13,14]. Both the priming and driving sections were filled with oxy-acetylene. For this design, the priming section was a 60.7 cm long and 16 mm inner diameter machined steel tube with the spiral groove machined to a depth of 0.36 mm on the inside of the tube. The driving section was 30.5 cm in length and 79 mm in inner diameter. This design did not employ a driven section. The reaction of the priming compound (0.04 g of lead styphnate) was initiated by impact, thus igniting the oxy-acetylene. As the fuel burned along the priming section, a deflagration to detonation transition (DDT) occurred. When the reaction reached the driving section, the energy was amplified by the additional volume of fuel in the driving section.

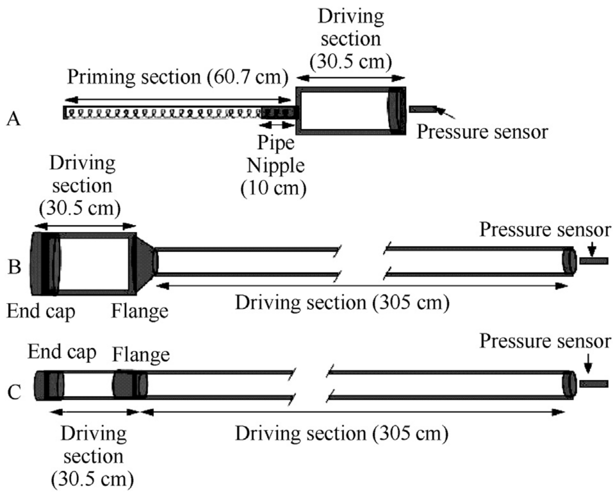

Fig. 1. Diagram of oxy-acetylene shock tube designs. A: Shchelkin spiral shock tube, B: Bottleneck shock tube, C: Solid fuel shock tube.