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Study of simple plane wave generator with an air-metal barrier

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Abstract

Plane wave generators (PWGs) are used to accelerate flyer plates to high velocities with their generated plane waves, which are widely used in the test of dynamic properties of materials. The traditional PWG is composed of two explosives with different detonation velocities. It is difficult to implement the related fabrication processes and control the generated waves due to its complicated structures. A simple plane wave generator is presented in this paper, which is composed of two identical cylindrical high explosive (HE) charges and an air-metal barrier. A theoretical model was established based on two different paths of the propagation of detonation waves, based on which the size of air-metal barrier was calculated for a given charge. The corresponding numerical simulations were also carried out by AUTODYN-2D® based on the calculated results, which were used to compare with the theoretical calculations. A detonation wave with a flatness of 0.039 μs within the range of 70-percent diameter of the main charge was obtained through the simulations.

Keywords: Explosion mechanics; Plane wave generator; High speed flyer

1. Introduction

Due to the requirements of the material processing and research on dynamic behavior of materials, the acceleration of high velocity projectiles [1−3] and various methods to obtain a plane wave [4−10] using high explosives have been studied in recent years. Plane wave generator (PWG) is a common explosion apparatus to generate a plane wave by controlling detonations of high explosive (HE) charges. The typical configurations of PWGs include two-component explosives, multipoint initiation, mouse trap and inert materials [4−10]. The two-component-explosive PWG, i.e., explosive lens, which consists of two explosives with different detonation velocities, was considered to be the most efficient way to generate plane waves [7,8]. This kind of PWG has been most widely used, however the corresponding fabrication processes and the control of detonation waves are difficult because of its complicated structures. Additionally, it is expensive.

In order to obtain simplified fabrication processes, a lower cost, and a plane wave with higher precision, there is a trend to replace the explosive with an inert material in the central wave-shaping mechanism. Sandia National Laboratory in USA manufactured a small-size PWG using brass as an inert material, in which the time difference of detonation wave generated can be less than 0.245 μs in the range of Φ20 mm [9]. Besides, plexiglass as an inert material was also studied by Chen et al. [4]. and Fritz [10]. The inert material can be produced by casting, which makes the fabrication process more conveniently with a smaller demand for charge. Additionally, the detonation waves generated by the PWGs with inert materials are more planar and more easily controlled.

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Generally, most of the above studies were concentrated on the curve surfaces of the inert explosives or materials. However, the fabrication would be simpler if the curve surface of the inert explosive or material could be replaced by a plane surface. Therefore, in order to design a simpler structure and obtain more plane waves, a simple plane wave generator with air-metal barrier was studied [11,12].

The simple plane wave generator is composed of two cylindrical charges and an air-metal barrier between them, as shown in Fig. 1. An important effect of the barrier is that a transmitted shock wave can be formed at the explosive-metal interface and then propagates in the metal media. On the other hand, when the spherical detonation waves are in contact with air, the detonation products expand at high pressure and velocity. Therefore, the main charge is initiated either by the shock wave or the detonation product. Since the velocity of a shock wave formed in metal is higher than that of detonation products expanding in air, the configuration of detonation waves is changed. Based on the above analysis, a spherical detonation wave can be adjusted to a quasi-plane wave.

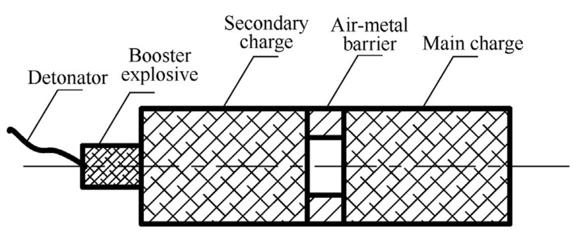

Fig. 1. Schematic diagram of a simple plane wave generator.

Aluminum is suitable for metal part due to its low density and high sound velocity. The simple plane wave generator with an aluminum ring was first designed by Yu and his colleagues [11], and the detonation waves with high flatness generated by the device were measured in their experiments. However, an important factor to the high flatness might be a large slenderness ratio (about 2) of charges used in their experiments, which would increase the curvature radius of the spherical wave and make it approximate to a plane wave. Zhao et al. [12] also designed a simple plane wave generator, in which the slenderness ratio of the HE charge is 0.6. The device was used in the test of the dynamic constitutive relationship of granite specimens. However, there have been few studies on the theoretical model and specific design method in the publications.

The objective of this paper is to design a simple plane wave generator with aluminum ring, in order to obtain more plane waves. Theoretical analysis and numerical simulations were both presented to determine structure parameters of this kind of PWG. The specific theoretical analysis is concentrated on two kinds of interfaces mentioned above, one is between the aluminum medium and explosives, and the other is between the air gap and explosives. Consequently, the size of aluminum ring can be calculated for a given charge. The numerical simulations were carried out by AUTODYN® with Lee-Tarver and JWL model based on the theoretical calculated results. Time difference was used to evaluate the flatness of detonation waves. The results provide the difference in generated detonation waves based on different sizes of aluminum rings. In addition, the simple PWG with an air-metal barrier can be designed for given charges.

2. Mathematical description of simple PWG with an air-metal barrier

In order to determine the size of an aluminum ring for a given charge, the propagation of the detonation wave in the PWG with an air-metal barrier was analyzed. Fig. 2 shows two different propagation paths of a detonation wave or a shock wave, i.e. $i \rightarrow o \rightarrow f$ and $i \rightarrow a \rightarrow e$. Here, OA, OB and OR are the detonation wave front, the transmitted shock wave front and the reflected shock wave front at the explosive–metal interface, respectively. Considering the disturbance of the outside rarefaction wave at the edge of the barrier and the complicated interactions at the aluminum–air interface in the barrier, for simplification, only the middle Point "o" of the bc segment is focused. On the other hand, the propagation path of a detonation wave from "i" to "a" in the secondary charge is the shortest. Thus, a quasi-plane wave can be obtained if the total time for the wave to travel along the two paths is equal.

2.1. Analysis of shock waves via the aluminum media

Assuming that the detonation is in a steady state after initiation and based on the geometric relation shown in Fig. 2, the time required for the detonation wave to arrive at point "o" is

$$t_{io} = \frac{L}{D\cos\varphi_0} \quad (1)$$

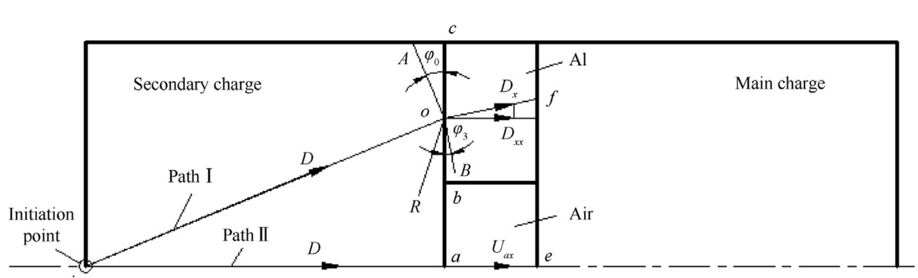

Fig. 2. Schematic diagram of the function principle.