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Formation features of cylindrical detonation wave at multipoint initiation

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Abstract. The experimental results showing the formation features of a cylindrical detonation wave with a multipoint initiation are presented in this work. One of the main features of the process is the presence of the “nodes” on the detonation wave, i.e. points of convergence of detonation waves from the neighbor points of initiation. The other feature is the presence of the “bundles” which are exeunt to the detonation products. Nodes are the points with high energy level at detonation front. They may cause hydrodynamic instabilities during the compression of a metal liner. Parietal flows in the cell structure of detonation products may be reason for formation of “bundles”. It should be noted that the detonation wave is always convex between the neighbor “nodes”, although in the initial moment the triple-wave Mach configuration is forming and it should lead to aligning of cylindrical wave. The experiments with the use of high explosives with different densities (from 0.95 to 1.65 g/cm$^3$) were carried out on the laboratory installation. The characteristic features of the detonation wave formed by the multipoint initiation can be seen both in solid and in liquid high explosives. Different design features (interlayers made of different materials etc.) did not lead to disappearing of “bundles” and smoothing of “nodes” at the detonation wave.

1. Introduction

Investigation of formation of cylindrical detonation wave by the multipoint initiation method appears to be of great practical importance. This paper presents the results of formation of cylindrical detonation wave in solid and liquid high explosive (HE). In our previous works [1–3] the authors experimented with cylindrical detonation wave, generated by the multipoint initiation, by utilizing custom designed laboratory setup in the presence of a small amount of the high explosive. It allowed to execute our work in explosion chamber the limit of weight of HE for which is 1 kg of trinitrotoluene (TNT). The registration was made by Nanogate 4BP high speed camera with the exposure time of 10 ns. In work [1] it was proven that, at multipoint initiation, detonation wave conjunction points are characterized by appearance of triple wave Mach configuration, which smooths out cylindrical detonation wave at the initial stage of formation. Complex picture of detonation products flow with volume cell structure is forming behind the detonation wave [4]. In addition, the work [2] presents mathematical modeling of cylindrical detonation, which predictions are in good agreement with the experimental results. This paper is sequel to the authors’ previous works.
2. Experiment

The geometrical size of the experimental setup is the same as in works [1, 3], but the number of the initiation points was increased from 24 to 48, i.e. initiation step was reduced to 14 mm (figure 1).

This greatly reduces the distance to the formation of the cylindrical detonation wave from the moment of initiation. But at the same time multipoint initiation detonation wave formation special features became more evident. One of these features is presence of nodes on the detonation wave, i.e. convergence points of detonation waves formed by adjacent detonators. Another feature is presence of the “bundles” (bright streaks) in the detonation products. Parietal flows in the cell structure of detonation products may be reason for formation of “bundles” [4]. Cell is a part of the detonation wave between two nodes. Detonation products from two neighboring cells are slide relative to each other, but do not mix and that flow mark boundaries. Another feature is the fact that the detonation wave is always convex between the neighboring nodes, although in the initial moment the triple-wave Mach configuration is formed and it must had led to alignment of cylindrical wave [5]. Experimental investigation of HE with varying density (from 0.92 to 1.65 g/cm$^3$) was carried out by utilizing special laboratory installation.

Figure 2 shows the detonation wave at HE with density of 0.95 g/cm$^3$ at 35 mm from the point of initiation. It should be noted that “nodes” (i.e. convergence points of detonation waves from the adjacent detonators) are visible at its surface. But the presence of “bundles” cannot
be seen quite clearly. Figure 3 shows the process of cylindrical wave formation in pressed charge with density of 1.63 g/cm$^3$. In this case “bundles” (parietal flows in detonation products) with complex configuration are clearly visible. Conjugation points i.e. “nodes” are clearly visible too.

In order to smooth the detonation wave converges in the center was mounted a cylindrical block with a charge density of 1.65 g/cm$^3$, and had placed in a copper shell 5 mm thick. Bulk charge was placed between the shell and points of initiation. The distance from the points of initiation to the copper shell was 49 mm, that is match more than triple distance between the initiation points (14 × 3 = 42 mm, the distance at what the detonation wave must stabilize according to work [5]).

Figure 4(a) shows that sufficiently smooth cylindrical detonation wave without visible features was formed in bulk charge. Figure 3 shows detonation wave that reached the pressed part of charge. That wave retained all the features mentioned above. One can see both “nodes” and “bundles”.

The original setup with 48 points of initiation was modified to see the process of cylindrical detonation wave formation in liquid HE (FEFO). In the center, concentrically with the initiation system was placed cylindrical cuvette for liquid explosives. Cuvette wall was made from the aluminum foil with the thickness of 0.4 mm. The bulk HE was placed between the wall and the points of initiation. The thickness of the wall was chosen with such a manner to ensure reliable transmission of detonation from bulk to liquid HE. The distance between the points of initiation and the wall of the cuvette was 54 mm. It was assumed that smoothed in bulk explosive detonation wave enters into another medium—the liquid explosive—and will take the form of a monotone. The results of observation are shown in figure 5.

In bulk charge at $t = 41 \mu s$ the wave is quite smooth and the “bundles” have fuzzy outline, but in liquid HE $t = 46 \mu s$ they are clearly visible. “Nodes” can be clearly defined either. It can be said that such a detonation wave retains its characteristics in the transition through the boundary of HE density or through a metal barrier.
3. Concluding remarks
Peculiarity features of the detonation wave formed by the multipoint initiation are observed both in condensed HE with different density and in liquid HE. It should be noted that at figures 2–4 where the “nodes” are clearly visible the detonation wave between them is always convex. Probably, the radius of its curvature equals to the distance from initiation point. But even triple wave Mach configuration which is forming in the beginning of cylindrical wave formation does not change the sign of curvature, i.e. does not smooth, as it was assumed in work [5]. Figure 6 shows the calculation of detonation products energy distribution according
to the model presented in work [2]. Figure 7 shows the impression of the impact of a cylindrical detonation wave with 24 initiation points on a steel plate. It is possible to observe radial lines that are a trace of the slip of “nodes” toward the center. It can be assumed, that high energy levels correspond to “nodes” on detonation wave. Upon compression of the cylindrical liner by the products of multipoint initiation of detonation at “nodes” will be a source of hydrodynamic instabilities that may lead to abnormal compression and release liner material into the interior volume. This adversely affects the compressed medium.

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