Smoothing the front of the detonation wave in experiments with multipoint initiation

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Abstract. An uncomplicated explosive technique, in which a detonation wave is formed using a multipoint initiation, has interesting features. One of them is a complex cellular structure, which consists of nodes and cords. The reasons of these features and ways of their elimination are discussed in the work. The study was carried out using a high-speed camera with nanosecond resolution. Methods for smoothing a detonation wave formed with multi-point initiation are presented.

1. Introduction

Multipoint initiation of an explosive charge is a way of generating detonation waves of various configurations. Cylindrical, conical, spherical and planar waves have found the wide application in different fields of science and technology [1–3]. Often they are used without their detailed consideration, which can lead to results that can be hardly explained. The waves that are formed by this method have a number of features, which are mentioned in the earlier works of the authors [4–6]. It should be noted that cylindrical detonation is a nonstationary process. Its velocity increases as the detonation wave moves towards the center.

In a previous work of the authors [4], it was shown that the method of multipoint initiation is the reason for the formation of a complex cellular structure of the wave and the flow of detonation products. The lines of nodes, which form the cells, and the intersection points of these lines are observed on the surface of the detonation wave in experiments with full-sized cylindrical charge. The shape of the cells will depend upon the initial location of the initiation points (rectangles, squares, triangles, etc) [7]. In detonation products, the cells are confined by the detonation wave and wall flows (cords), which begin from the node line. These streams look like bright bands and remain until full compression. A characteristic feature of the nodes is the local increasing of pressure [5]. One of the most common tasks is the compression of the metal liner by detonation products. In this case, the output of such a shock wave on the free surface of the liner can cause hydrodynamic instabilities along the line of nodes. Such instabilities will only increase with compression. In addition, the emission of target material particles into a compressing volume is possible along the line of nodes and especially at the intersections of these lines, which must be taken into account when solving the particular practical problems [8–10].

Therefore, the work discusses the ways of smoothing the detonation wave obtained by the multipoint initiation method. We can suggest two ways to improve the form of the detonation wave. The first is to obtain a detonation wave with minimal perturbations (nodes) during its
formation. The second is the damping of the detonation wave after its formation. In this paper, the first way will be considered. The laboratory facilities for the formation of a cylindrical and flat detonation waves by the method of multipoint initiation give a complete picture of the processes of interest. The second way is of great practical importance, but it is very complicated.

2. Experimental
All the experimental studies were carried out with laboratory facilities for the generation of a cylindrical (figure 1) or a flat detonation wave by the method of multipoint initiation, and they are presented in the works of the authors [4, 6].

The formation of a cylindrical detonation wave by the method of multipoint initiation is shown in figure 2, where four successive frames are imposed at regular intervals. At the time of $33 \mu s$, initiation of the main charge begins. The beginning of conjugation of detonation waves from neighboring initiation points can be observed at the second frame $38 \mu s$. It is likely that at this time a three-wave Mach structure begins to form, the leg of which has an increased pressure and accelerates the detonation wave in this region (see figure 2, 43-th $\mu s$). It should be noted that the central axis of the detonation wave at $43 \mu s$ is on the axis of the conjugation line. On the fourth frame, at the time $48 \mu s$, the generated detonation wave is shown.

It was assumed that the detonation wave formed in this way has a smooth structure (see figure 2, 48-th $\mu s$) and will be maintained until the complete collapse. To confirm this fact.
Figure 2. Formation of a cylindrical detonation wave by the method of multipoint initiation: 1—33 $\mu$s, ignition of initiators; 2—38 $\mu$s, the moment of conjugation of detonation waves from neighboring initiation points; 3—43 $\mu$s, wave smoothing due to the three-wave Mach structure; 4—48 $\mu$s, formed detonation wave.

Figure 3. The detonation wave in the indicator charge, the arrow indicates the direction of motion of the wave: 1—shock wave on a copper liner; 2—undisturbed part of the indicator charge; 3—detonation wave in the indicator charge; 4—nodes; 5—cords.

an indicator pressed charge was placed in the central part of the laboratory assembly. In the charge, the complex structure of the detonation wave with nodes and cords is clearly displayed. Figure 3 shows the results of such an experiment. A smooth detonation wave came to the indicator charge and transformed into a smooth shock wave (see figure 3, shock wave on a copper liner). Then, during the entrance to the indicator charge, a detonation wave, which has a characteristic cellular structure with nodes and cords, was formed (see figure 3).
Figure 4. The cage and one cell (increased): 1—point of initiation; 2—foam; 3—explosive.

Figure 5. The detonation wave, formed with the use of the clip, enters the indicator charge, the arrow indicates the direction of motion of the wave.

One of the reasons for the cellular structure of the detonation wave is the presence of nodes. They are formed by conjugation of detonation waves from the neighboring initiation points at the initial moment (see figure 2). To reduce the values of pressure and temperature of nodes, it was suggested that the interaction of waves from neighboring initiation points takes place not in an explosive, but in a low-dense neutral medium. A clip of foam was installed in the laboratory assembly to this end (figure 4). The initiation point (see figure 4) excites detonation in the explosive substance of the conical cell. Shock waves from the neighboring initiation points interact in a foam It is assumed that the intensity of the nodes should be greatly reduced.

Figure 5 shows a frame-by-frame detonation wave formed by a foam clip (see figure 4) in an indicator charge in the center of the assembly. At the time $41 \mu s$ (see figure 5), the detonation wave approaches the indicator charge, having a weakly displayed cellular structure. The passage through a thin copper cage and the initial moment of entering the indicator charge are shown at $44 \mu s$. The motion of detonation wave through the indicator charge is shown at time $46 \mu s$.

We can say that the detonation wave when moving along the indicator charge is sufficiently smooth and does not have a noticeable cellular structure, as is clearly seen in figure 3. This
assumption was also confirmed during the formation of a flat detonation wave by the method of multi-point initiation using foam inserts. The results are shown in figure 6.

3. Conclusions
When solving some problems associated with the use of detonation waves of various shapes (cylindrical, planar, conical, spherical, etc), formed using the multi-point initiation method, the wave structure, at first glance, may not have a significant value. And with a more detailed examination of the problem, the cellular structure of the wave can cause many undesirable phenomena, such as hydrodynamic perturbations that progress in compression, ejection of plasma and particles of compressible material, and others. And most importantly, this structure is maintained throughout the entire process. In this connection, the method of smoothing the cellular structure was proposed and substantiated. The conjugation of shock waves from the neighboring initiation points at the initial instant of time occurs in a porous low-density material, such as foam, which greatly reduces the intensity of the interaction. The experimental results are presented for cylindrical and planar detonation waves formed by the method of multipoint initiation. They are obtained on laboratory installations. These results show the correctness of the chosen direction.

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