The formation of a detonation wave with multipoint initiation

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Abstract. The results of experimental investigations of the formation of detonation waves with multipoint initiation for the case of a planar and converging cylindrical wave are presented. A special initiation system was used, where the main element was modeled for manufacturing on a three dimensional printer. A solution was found to form a smooth detonation wave for the planar case. Studies of a converging cylindrical detonation wave have shown the need to solve some fundamental issues related to the nonstationarity of such a wave.

1. Introduction
To solve many practical and scientific problems associated with the use of explosive techniques, there is a need to use detonation waves of various shapes (cylindrical, planar, conical, spherical, etc). One of the simplest methods for the formation of such waves is the multipoint initiation method. This work is a continuation of the experimental studies of the authors.

In [1–3], the presence of a rather complex structure of such a wave was shown. In [4], the causes of the formation of such a shape and the ways of smoothing its complex volume-cellular structure are determined, since it is the cause of many undesirable phenomena. These include hydrodynamic perturbations on the surface of a compressible liner, the ejection of plasma and material particles into the volume under study, and others [5–7]. The results of experimental studies of the formation of a detonation wave at the initiation stage are presented in [8]. The interaction of shock waves from neighboring points of initiation at the initial moment of time occurs in a porous low-dense material, such as foam plastic, which greatly reduces the intensity of interaction.

In this work, the results of two series of five experiments each are presented.

2. Experimental
It is proposed to apply the initiation points of a special form. Such a model for the formation of a planar detonation wave for 7 points of initiation is shown in figure 1. A single cell is a hollow bell, about 0.5 mm thick. In the lower section of the bell has the shape of a circle, gradually turning into a square in the upper section. The diameter of the lower part is of about 5 mm. It is determined by the diameter of the point of initiation.

The evolution of the formation of a planar detonation wave using multi-point initiation sockets (7 initiation points) is shown in figure 2. Photo registration was carried out using the domestic high-speed camera “Nanogate-4BP”, the parameters of which are presented in [1]. The side of...
the upper section is determined by the thickness of the charge and is approximately 17 mm. The length of the socket will determine the radius of curvature of the detonation front at the exit and is approximately 30 mm.

Such an initiation system is made of polymer on a three dimensional printer. Into the openings of all sockets enter the points of initiation and the sockets themselves are filled with plastic high explosive (HE). This HE has the following parameters: density—1.5 g/cm$^3$, detonation velocity—7.5 km/s, failure diameter—1 mm. The stripe of the wide parts of the sockets comes into direct contact with the explosive, where a planar detonation wave should be formed. In the case of simultaneous initiation, the initial stage of the interaction of shock waves from neighboring points occurs not in the explosive but in air, which significantly reduces the intensity of the interaction. When detonation waves exit the sockets directly into the charge, they interact at lower angles. It is possible that this will not lead to the formation of “nodes” [1] when propagating along the main charge.

At a time of 25 $\mu$s, detonation waves emerge from the sockets with a time difference of about 70 ns. At 26 $\mu$s, it can be seen that the fronts of individual waves are straight, the conjugation points are observed, but they are rather weak. At the time point of 27 $\mu$s, weak kinks can still be observed at the junction points and “cords” [1]. At 32 $\mu$s, the wave is smoothed and one weak “node” remains noticeable in the region of the greatest time difference between the detonation waves leaving the initiation system.

The formation of a converging cylindrical detonation wave by the method of multipoint initiation using a special system with sockets was observed on the experimental assemblies presented in figure 3. A system of initiation is located around a pressed cylindrical charge with a diameter of 100 and a thickness of 17 mm [figure 3(b)]. It consists of 20 sockets with explosives, the same as for the initiation of a planar wave. The difference lies in the fact that the upper part of the socket has a cylindrical surface that fits tightly to the surface of the charge. All sockets form a cylindrical surface with a diameter of 100 and a width of 17 mm. All sockets are
Figure 2. Evolution of the detonation wave in a planar statement (the wave moves from right to left).

Figure 3. (a) Side and (b) top views of the experimental assembly.

initiated simultaneously from one detonator and detonation cords of the same length located in the lower part of the assembly [figure 3(a)].

The results of this assembly are shown in figure 4. High-speed photography of the evolution of a converging detonation wave with multipoint initiation was also carried out using the high-speed camera “Nanogate-4BP”.

At the moment of time of 32.5 $\mu$s, it can be observed that the initiating pulse through the detonation cords is inserted into all the sockets of the initiation system. In the next frame (of 33.5 $\mu$s), it can be seen that the detonation waves from each socket enter the charge. The formation of “nodes” is observed at the junction points of neighboring detonation waves. The aggregate detonation wave takes the form of a polygon, the sides of which are concave toward the center. At time points of 34.5 and 36 $\mu$s, the characteristic features of the shape of a converging
detonation wave remain the same. In addition, the “cords” are clearly displayed in the last frame (of 36 µs), which indicates the preservation of the “nodes”. These facts confirm that a smooth cylindrical detonation wave did not form.

3. Conclusions
Based on experimental studies of the formation of a detonation wave by the method of multipoint initiation, it can be assumed that the use of a special initiation system (the use of sockets) does not always lead to the desired result. When a planar detonation wave is formed, it is possible to obtain its smooth surface, i.e., without “nodes”, provided that the time difference between the trigger points is less than a certain value, in this case less than about 70 ns.

For a converging cylindrical detonation wave formed by the multipoint initiation method with sockets, its complex structure with “nodes” and “cords” is maintained throughout the convergence process. Perhaps the reason for this is the unsteady mode of a converging detonation wave, while a planar detonation wave propagates in a stationary mode.

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References
[1] Dudin S V, Sosikov V A and Torunov S I 2016 J. Phys.: Conf. Ser. 774 012074
[2] Shutov A V, Sultanov V G and Dudin S V 2016 J. Phys.: Conf. Ser. 774 012075
[3] Dudin S V, Sosikov V A and Torunov S I 2016 Experimental investigation of cylindrical detonation wave U781 Uspekhi Khimicheskoi Fiziki: Sb. Tezisov Dokladov na III Vserossiyskoy Molodezhnoy Konferentsii, 3-7 Iyulya 2016 g. ed Aldoshin S M et al (Moscow: Granitsa) p 39
[4] Dudin S V, Sosikov V A and Torunov S I 2018 J. Phys.: Conf. Ser. 946 012057
[5] Dudin S V, Kulish M I, Shutov A V and Mintsev V B 2012 Investigation of exit of strong shock wave at free surface of metal Int. Conf. on Shock Waves in Condensed Matter (Kiev, Ukraine: Interpress Ltd) pp 231–8
[6] Kulish M I, Mintsev V B, Dudin S V, Ushnurtsev A E and Fortov V E 2011 JETP Lett. 94 101
[7] Kulish M I, Dudin S V, Ushnurtsev A E and Mintsev V B 2018 J. Phys.: Conf. Ser. 946 012042
[8] Sosikov V A, Torunov S I and Dudin S V 2019 J. Phys.: Conf. Ser. 1147 012027

Figure 4. The evolution of a converging detonation wave with multipoint initiation.