



Research paper / Praca doświadczalna

Some aspects of detonation transmission in the shock tubes of a non-electric initiation system (NIS) *Niektóre aspekty przeniesienia detonacji w rurkach detonujących systemu inicjującego (NIS)*

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Abstract: Under laboratory conditions, experimental studies were conducted on the propagation patterns of a stable detonation front in a coaxial shock tube under complex conditions which pose a risk to the integrity and uniformity of the explosive deposited on its inner surface. A design for a switching unit which guarantees branching of the explosive network, is proposed.

Based on the experimental studies conducted, the critical parameters associated with the non-uniform distribution of the explosive along the inner surface of the shock tube shell are identified. The design principles for employing passive switching units to branch the detonation process in modern initiation systems were justified.

An improved explosive network employing passive connecting devices enables stable transmission of detonation to four shock-tube branches simultaneously without the use of a blasting cap. The proposed solution has practical significance for switching surface networks of industrial charges and for applications involving dispersed borehole charges, while substantially reducing shock-tube system cost.

Streszczenie: W warunkach laboratoryjnych przeprowadzono badania eksperymentalne dotyczące wzorców propagacji stabilnego frontu detonacji w rurce detonującej w złożonych warunkach, które stwarzały zagrożenie dla integralności i jednorodności rozpylonego materiału wybuchowego na jej wewnętrznej powierzchni. Zaproponowano projekt układu przełączającego, który gwarantuje rozgałęzienie sieci ładunków wybuchowych.

Na podstawie przeprowadzonych badań eksperymentalnych zidentyfikowano parametry krytyczne związane z nierównomiernym rozkładem materiału wybuchowego wzdłuż wewnętrznej powierzchni rurki detonującej. Uzasadniono zasady projektowania wykorzystujące pasywne układy przełączające do rozgałęzienia procesu detonacji w nowoczesnych systemach inicjowania.

Ulepszona sieć ładunków wybuchowych wykorzystująca pasywne elementy łączące umożliwia stabilną transmisję detonacji do czterech gałęzi rurki detonującej jednocześnie, bez użycia splotki. Proponowane rozwiązanie ma praktyczne znaczenie dla przełączania sieci powierzchniowych

ładunków przemysłowych oraz zastosowań z rozproszonymi ładunkami wiertniczymi, przy jednoczesnym znacznym obniżeniu kosztów systemu rurek detonujących.

Keywords: *detonation, shock tube, spraying, shock wave, detonation transmission, passive splitter (switcher)*

Słowa kluczowe: *detonacja, rurka detonująca, rozpylanie, fala uderzeniowa, przenoszenie detonacji, pasywny rozdzielacz (przełącznik)*

1. Introduction

Relevance. The primary direction of engineering developments to reduce the cost of detonation components of modern explosive networks is to establish the mechanism of development and conditions for the attenuation of the shock wave front in the shock tube shell material, as well as the regularities of the formation of the detonation process along the length of the shock tube. To maintain this process at a constant level at the junctions and branches, it is necessary to consider the consequences of non-standard situations in mass production and the use of the detonating shock tube during its transmission. This will improve the technology of charging and explosive works, including through the use of passive switching units.

Purpose. Experimental studies of the transmission modes of the detonation process in the system of detonating shock tubes with the aim of improving the technological parameters of modern low-speed initiating systems of the *Nonel* type.

Literature review. A comprehensive approach to permanently solving the problem of increasing the safety of blasting operations, is possible by reducing the detonation rate of initiating devices and industrial explosives at all stages. As a result of the development and improvement of non-electric initiation systems for explosive charges, several systems have been created and used internationally. The *Nonel* system has the most widespread application. Non-electric initiation systems, compared to electric ones, provide a broader range of achievable delay times and, in some cases, are more economical [1-3]. The company *Nitro Nobel AB* produces several modifications of the system [4-10].

The analysis indicates that use of the *Nonel* system reduces blasting costs and increases the monthly advance of the underground working face by 10-30% relative to electric initiation systems. A previous gap in Ukrainian explosive technology for initiating industrial charges has been successfully closed in recent years by the production of a Ukrainian analogue of the internationally dominant non-electric initiation system based on a detonating tubular shock tube [6]. The theoretical validation of the wave dynamics in the plastic shell of a detonating shock tube, and the practical development of a domestic coaxial detonation wave translator, should be considered a significant achievement of Ukrainian scientists and engineers [7]. Their work was conducted in the context of an almost complete absence of information on the operating mechanism of non-electric low-speed initiation systems, the theoretical description of the physical processes occurring in a detonating shock tube, and the specifics of its manufacturing technology [8]. Related studies were devoted to establishing the conditions required for maintaining a stable detonation process in a shock tube with non-uniform deposition of the detonating composition onto the surface of the coaxial channel, as well as using the obtained data to develop the design parameters of a passive detonation splitter for the implementation of an economical method of switching the initiating system of industrial charges under conditions of a mass explosion.

2. Results and discussion

2.1. Dynamic parameters of a detonating shock tube

The experimental determination of the detonation velocity (V) in the shock tube under study was performed on a 585 mm long tube (Figure 1). Figure 2a – shows the oscillograms of piezoelectric sensors 1 and 2, recorded on the oscilloscope C 9-8, and Figure 2b – on the oscilloscope C 9-16. The detonation velocity

between sensors 1 and 2 is:

- according to oscilloscope C 9-8: $V = 1852$ m/s,
- according to oscilloscope C 9-16: $V = 1734$ m/s,
- the average detonation velocity from the two oscilloscopes is: $V_{av} = 1793$ m/s,
- the number of parallel studies in all cases was at least three.

During the experiments, the detonation-wave pressure was measured at the end of the shock tube. Piezoelectric sensors and a pressure sensor were installed on the tested shock tube as shown in Figure 3. The detonation pressure was measured using sensors 1 and 2 (Figure 4). The measurements showed that the pressure in the reflected wave at the end of the shock tube was 3.26 MPa.



Figure 1. Scheme of experiments with a detonating shock tube: A – point of application of the initiating electric explosion, 1 and 2 – piezoelectric sensors

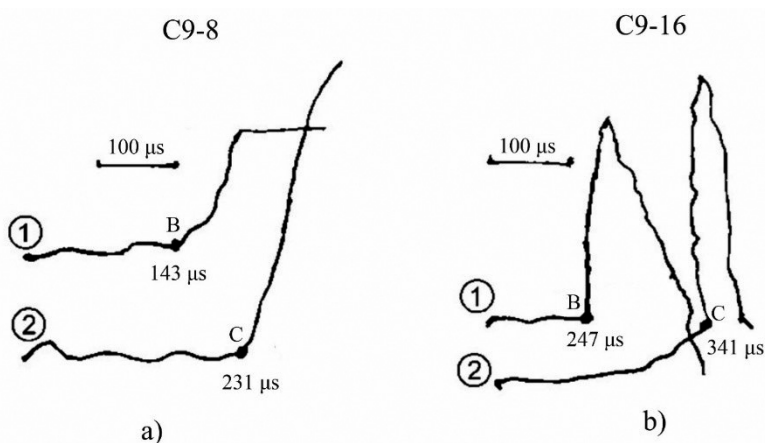


Figure 2. Test results of the detonating shock tube: a – piezosensor 1, b – piezosensor 2

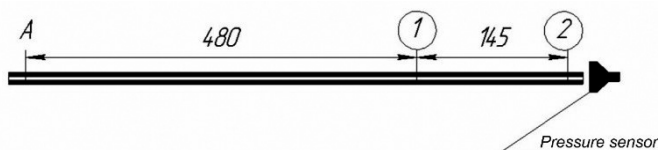


Figure 3. Scheme of piezosensors and pressure sensor placement

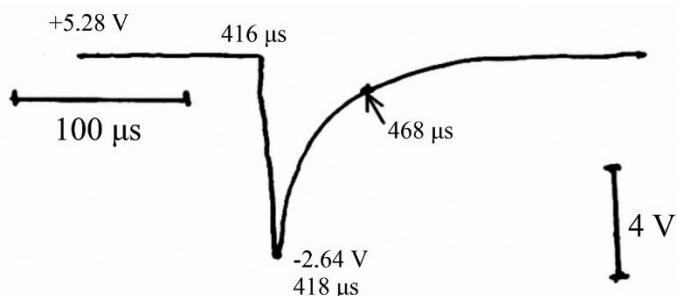


Figure 4. Pressure oscillogram

The average detonation velocity in the area between the 1st and 2nd sensor was 1700 m/s. At the same time, the speed of propagation of mechanical disturbances from the place of the electric discharge was 1200 m/s. It is necessary to consider the possibility of short-term interruptions in the dosing of the detonating composition. In such a situation, areas with a reduced amount of detonating composition may form on the inner surface of the shock tube channel. To determine the detonation transmission distance, experiments were conducted (Figure 5) on domestic and imported samples of shock tubes from the Dyno Nobel company.

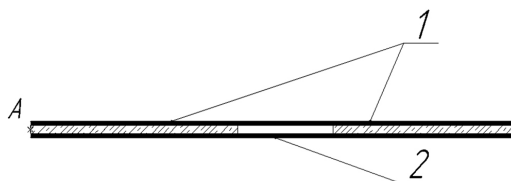


Figure 5. Scheme of experiments on the transmission of detonation through an inert gap: 1 – shock tube with sprayed detonating composition, 2 – inert gap (shock tube segment without spraying)

Experiments established that the maximum length of the unsprayed shock tube, through which detonation can still propagate, is 20 cm for the domestically produced tube and 22 cm for the Dyno Nobel tube. During a short-term decrease in dispenser productivity, the linear density of the composition is reduced. To qualitatively determine the minimum linear density at which detonation can be maintained without applied explosive (Figure 6), inserts were made in the area between two sections of the shock tubes, in which a small section of the shock tube alternated with an uncoated tube. It was established that when the linear density of the detonation composition application is reduced by 33% of the standard application density (25 mg/m) on a section up to 2 m, the detonation can still be transmitted, which indicates high reliability of shock tube functionality.

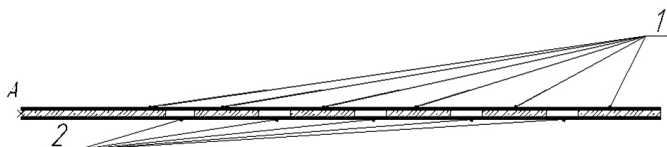


Figure 6. Scheme of experiments to determine the minimum linear density of the detonating composition in a shock tube: 1 – shock tube with sprayed detonating composition, 2 – inert gaps

2.2. Study of the process of detonation transmission to the shock tube through a passive splitter

Structurally, the detonation process splitter (passive switch) can be represented in simplified form as a metal tube, into which the end of the detonating shock tube segment is inserted, with two similar tubes serving as outlets for the detonation-transmitting segments. The system is rigidly connected and forms a tee configuration (Figure 7). After studying the pressure pulse entering the metal tee (splitter), experiments were performed to investigate the process of detonation transmission through the metal tee. Piezoelectric sensors and a pressure sensor were installed as shown in Figure 7.

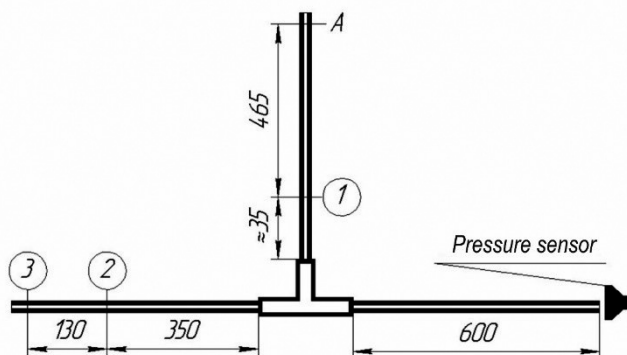


Figure 7. Sensor placement diagram for experiments with a splitter: A – initiation location, 1, 2 and 3 – locations of piezosensors

After initiation, detonation propagated from the initiating section of the shock tube into all three segments. In Figure 8, the oscilloscope's upper trace corresponds to the pressure sensor, while the lower trace corresponds to the piezoelectric sensor. On the C 9-16 oscilloscope, the upper trace was connected to sensor 2 and the lower trace to sensor 3 (Figure 8). According to the obtained oscillogram, the maximum pressure in the reflected wave was 6.5 MPa. The average propagation velocity of the detonation process from piezosensor 1 to the end of the tube, taking into account the passage through the triple splitter, was 1242 m/s, indicating a slight reduction in detonation velocity across the splitter.

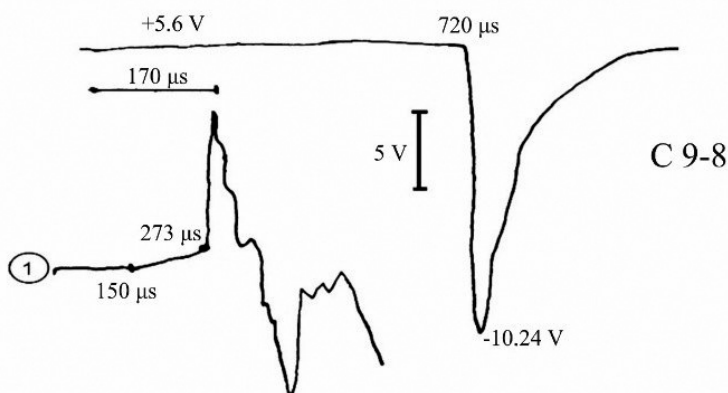


Figure 8. Oscillograms from sensor 1

Figure 9 shows the oscillograms for piezosensors 2 and 3, taken from oscilloscope C 9-16. The average velocity of the detonation transmission through the triple splitter in the section between sensors 1 and 2 was 1225 m/s. Comparison of the measured velocities shows that detonation transmission occurs simultaneously in the right and left branches of the triple splitter. In the section between sensors 2 and 3, the detonation speed increased to 1805 m/s.

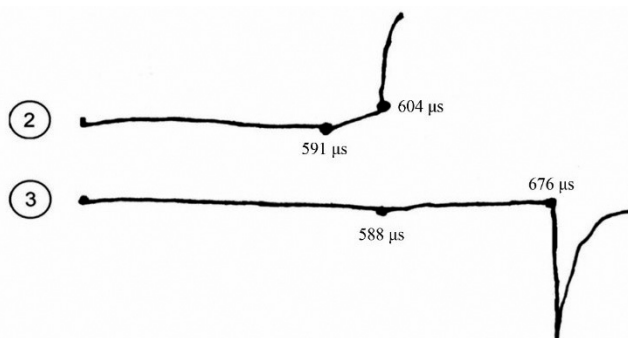


Figure 9. Oscillograms from the oscilloscope C 9-16

Because deformation of the shock-tube segment, which was detected by the piezoceramic sensor, is induced by an internal dynamic load propagating ahead of the detonation front, this effect was verified experimentally. For this purpose, at the right end of the shock tube exiting the triple splitter, a piezoceramic sensor 2 was installed in the same configuration as pressure sensor 1, i.e., with a gap from the tube end equal to the thickness of the blade (Figure 10). The readings of sensors 1 and 2 are shown on the oscillograms (Figure 11). At the peak of the pressure wave, pressure sensor 2 registered a pressure of $P = 5.4$ MPa.

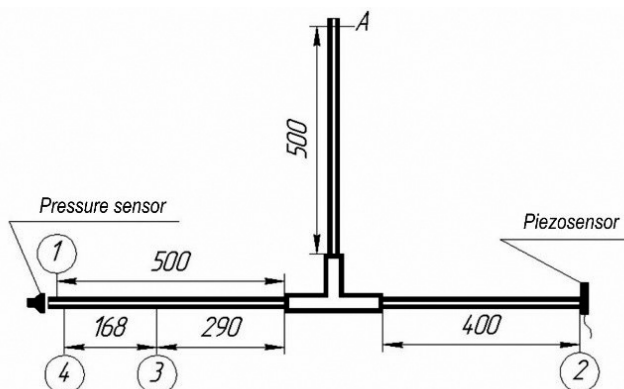


Figure 10. Sensor placement diagram for measuring pressure at the end of the shock tube

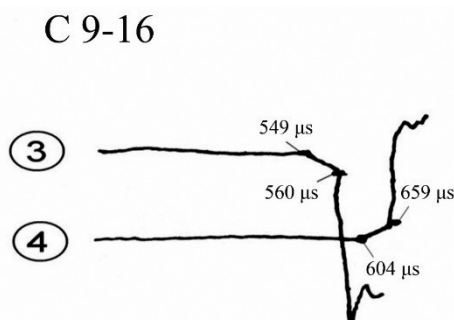


Figure 11. Oscillograms obtained from sensors 3-4

As can be seen from the analysis of experimental data (Figures 2, 4, 8, 9, 11), when transmitting detonation through a triple splitter, it takes about 125 μs for acceleration and formation of detonation waves in the sleeves of the triple splitter of these parameters. In practice, no more than three downhole tubes and one shock tube are connected to a single block, so additional block types were tested. These blocks allow connection of up to five shock-tube segments, one of which serves to transmit detonation simultaneously to four branches. The switching blocks were made of rubber, copper, aluminum, steel, plexiglass, high-impact polystyrene, fluoroplastic, and PVC. In all cases, the experimental results were positive. During the experiments, it was established that as the number of shock-tube segments to be initiated increases, the distance between the initiating end and the ends of the initiated segments must be reduced.

3. Conclusions

- ◆ Detailed studies of the Ukrainian made tube revealed several essential regularities and conditions for the development and transmission of the detonation process in the switched shock tube system. The constant velocity of the detonation front was about 1800 m/s.
- ◆ During the study of detonation transmission in the shock tube system through a non-detonating triple splitter, it was found that the detonation process develops simultaneously in the right and left branches of the splitter, with the velocity decreasing to ~ 1200 m/s at the branching node. In the downstream branches, the velocity increases and is set at an average level of ~ 1800 m/s.
- ◆ Experiments further showed that when switching blocks (splitters) were manufactured from different materials, the Ukrainian shock tube stably transmits detonation through an unfilled explosive section of the connecting device cavity for a distance of no more than 150 mm.
- ◆ Experiments demonstrated that the device enables reliable transmission of detonation into four shock tube sections.
- ◆ Based on the experiments, it can be concluded that initiating dispersed charges and preventing shock tube bumping can be done by using switching blocks without a blasting cap, which also provides a noticeable reduction in shock tube costs, most notably in applications involving well-charge dispersion.

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Received: September 26, 2025

Revised: November 16, 2025

First published on line: December 30, 2025