

SHOCK-WAVE INITIATION OF A HIGH-EXPLOSIVE CHARGE TO CREATE AXIALLY SYMMETRIC DETONATION FRONT

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1. Introduction

Helical flux compression generators (HFCG) initiated at one end are well-studied and widely used. They have a relatively high initial inductance (100 μH) and a long operation time (100 μs) limited by the speed of the contact point motion. But there are a number of applications in which a shorter operation time (10 μs) is required. Such operation time is achievable using HFCGs with simultaneous axial initiation of an explosive charge, described, e.g., in [1, 2]. The explosive charge therein is initiated via a chain of electric detonators. To achieve homogeneity and symmetry of the armature expansion in this case, one should use detonators with the function time simultaneity $< 0.2 \mu\text{s}$. Such detonators exist, but are sometimes unavailable to research teams. General industrial detonators have the function time simultaneity $\sim 10 \mu\text{s}$ and cannot be applied.

However, detonation of condensed explosives can be initiated by any intense external action initiating a fast chemical reaction accompanied by a sustained shock wave. Detonation of primary explosives can easily be initiated by shock, friction, or heat. Secondary (brisant) explosives can also be initiated by firing, heating, or a strong shock, but a sustainable detonation thereof is only possible under favorable conditions, the most important of which is a high external pressure produced, e.g., through combustion of the explosives in a closed metal shell. The most reliable way to initiate detonation in secondary, brisant explosives is shock action.

A shock wave can be generated by the explosion of primary explosives, spark discharge, electrical explosion of wires (EEW) [1], or high-velocity impact of a thrown shell. Electrical explosion of wires is accompanied by a shock wave, dispersion of metal, and fast expansion of boiling metal drops and vapor into the ambient, occurring along the whole wire length. With EEW ignition the temperature at a shock wave front reaches 10^4 K , and the pressure amplitude in the ambient can be as high as 1.5 GPa, depending on the supplied energy and the material of the wire, as well as its diameter and length. These values are high enough to initiate detonation in sensitive condensed explosives. High temperature of dispersed molten metal drops also serves to initiate detonation in explosives. Discharge processes could also contribute. But contributions to the above phenomena in detonation initiation are the subject of special research.

Seeking to provide homogeneity and symmetry of the armature expansion, we developed a shock wave unit using electrically exploding wire for initiating high-

explosive (PETN or HMX) charges to create an axially symmetric detonation front. The detonators were made and tested in two designs.

The present paper reports the design details and the results of experiments.

2. Configuration Design

A high-voltage lengthy detonator using an electrically exploding wire of 100–500 μm was developed. Pentaerythritol tetranitrate (PETN) was selected as a sensitive explosive for the detonator for being technologically safe and widely used to load industrial detonators and detonating cords. It has a small critical diameter of the charge that depends on its granulometric composition and is about 0.70–0.86 mm for particle size of 0.025–1.0 mm and 2.1–2.2 mm for particle size of 0.15–0.25 mm [5].

Two detonator modifications were made:

- type detonator: detonating composition is ignited by a shock action via an intervening medium (3-mm-thick plexiglas) (Fig.1)
- type detonator: dense explosive charge is initiated by a high-velocity impact of a thrown shell (Fig.2).

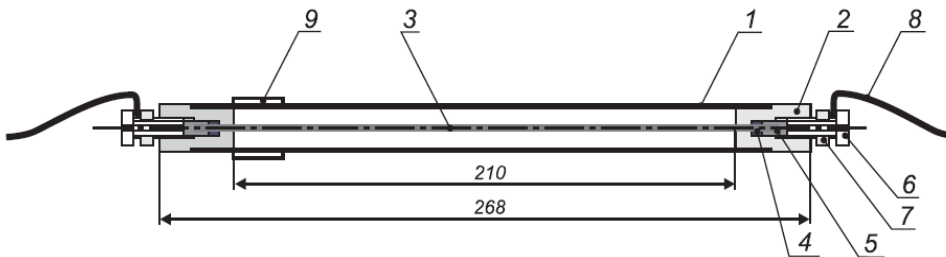


Fig. 1. Design of A-type detonator

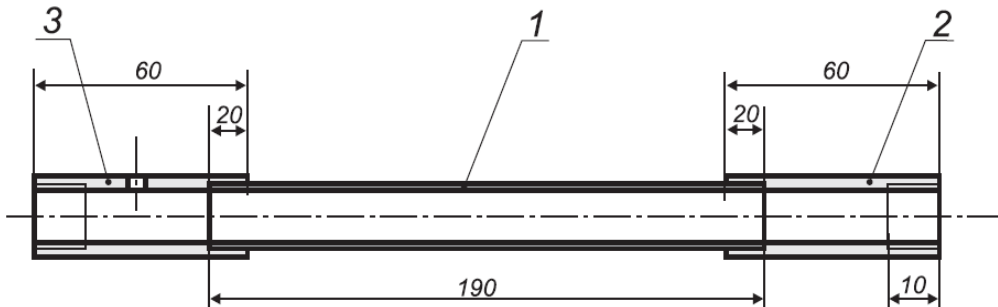


Fig. 2. Design of B-type detonator

A-type detonator (Fig. 1) consists of casing 1 made of a transparent cylindrical, plexiglas shell with the outer and inner diameters of 12 mm and 6 mm, respectively. A duct in the detonator casing is filled with the powder explosive, and then the casing is hermetically sealed by sealing sleeve 9. The transparent casing enables checking the tension and the continuity of wire 3, whose position is rigorously specified: it cannot deviate from the axis or sag in the central section. The current is driven to the wire by

means of two end plugs 2 having the same thread pitch, but the opposite-hand thread forms. This design feature makes it possible to avoid torsional strain when stretching the wire before compacting the charge. The wire is connected to the end plugs by clamps 6 via copper powder 5 (grain size is less than 100 μm) and insert 4. The power source is connected to the end plugs by insulated multifilament copper leads 8 with a 2.5 mm² cross section conductor. The leads are fixed with screw nut 7.

The modified version of the detonator (B-type detonator) comes from the need to initiate high-density explosives (1.4 g/cm³ and more), because the energy of a shock wave propagating in a high-density intervening medium is dissipated, and the secondary charge may not be initiated even under stable initiation of detonation in the explosive charge of the detonator.

A higher initiating power of B-type detonator (Fig. 2) is achieved by initiating the detonation in a high-density charge by a high-velocity impact of a 0.5 mm thrown shell made of aluminium AMC alloy. The modified casing is made up of thrown shell 1 and dielectric extenders 2 and 3, whose outer diameter is larger than the outer diameter of casing 1, thus forming an air gap between the surface of the ductile thrown shell and the initiated explosive charge, where the thrown shell is accelerated. Aluminium was chosen as a shell material for its small density and high ductility that permit high velocity impact with the initiated charge and prevent damage of the shell integrity as the shell flies.

The detonator is made in two stages:

- Assembly and preparation for loading the explosive,
- Compaction of condensed highly brisant explosive to form a blasting cap of the detonator.

The assembly begins with mounting the end plug on the one end of the detonator casing. Then we thread the exploding wire through the punch mark in the end plug and the duct of the detonator. The wire is fixed on the end plug. The other end of the wire is threaded through the punch mark in the other end plug, and the plug is then mounted onto the other end of the casing. The wire is fixed to the other end plug. The punch marks on the end plugs are then hermetically sealed. The wire is stretched by counter-clockwise rotation of the casing at a stationary position of the end plugs. No wire sag is allowed. If the wire is broken, the detonator is disassembled and the broken wire is replaced. Powder PETN preparation before compaction consists in size grading and checking for foreign inclusions: the size of PETN fractions is less than 200 μm . The explosive is compacted using a vibratory table.

3. Experiment

A low inductance 10 μF capacitor bank feeds the electrically exploding wire installed in the detonator via a 33 m long high-voltage coaxial cable. Copper wire with a diameter of 315 μm and a length of 210 mm is used in all the experiments. The applied voltage, which in all our experiments equals 15 kV, is matched to provide the current through the wire sufficient for initiation of PETN charge by wire explosion. The current in the circuit is measured by Rogowski coil. Optical pins are used as time-of-arrival detectors to control:

- electric explosion of wire inside a transparent detonator shell without explosive charge;
- simultaneity of initiation of the detonator charge along its whole length;
- simultaneity of initiation of the main charge in the armature tube by a lengthy detonator.

Step 1. Observation of the electric wire explosion using optical pins. The experimental layout (Fig.3): A-type detonator, whose casing is made of a transparent material (plexiglas), without explosive charge with three optical pins spaced 70 mm apart from one another. The graphs in Fig. 4 show the discharge current and the signals from the optical pins versus time.

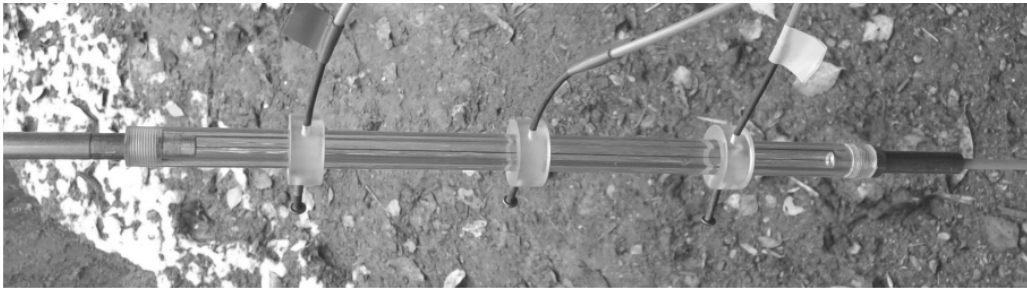


Fig. 3. A-type detonator, whose casing is made of transparent material (plexiglas), without explosive charge

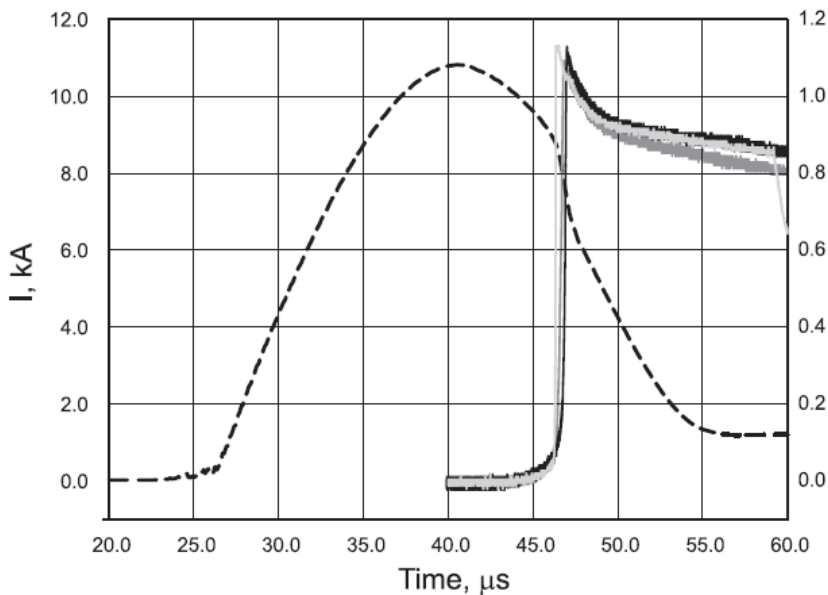


Fig. 4. Discharge current (dashed curve) and three signals from optical pins (solid curves) at explosion of a copper wire in the duct of A-type detonator

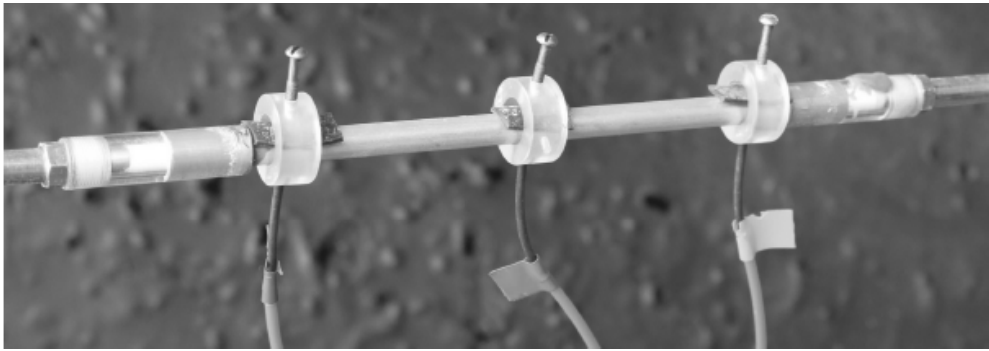


Fig. 5. B-type detonator with explosive charge

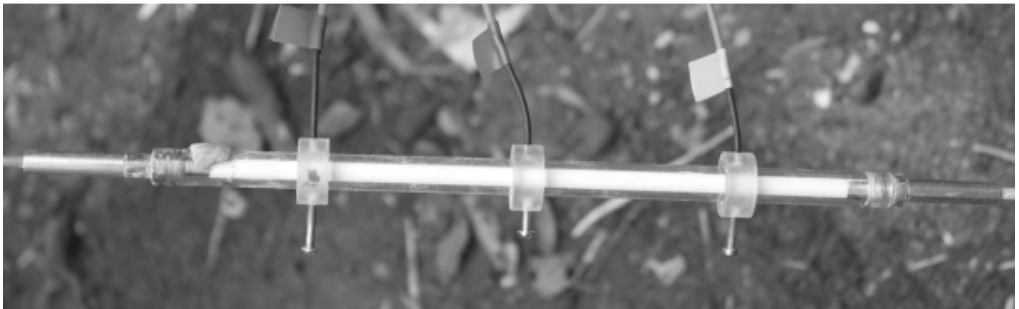


Fig. 6. A-type detonator with explosive charge

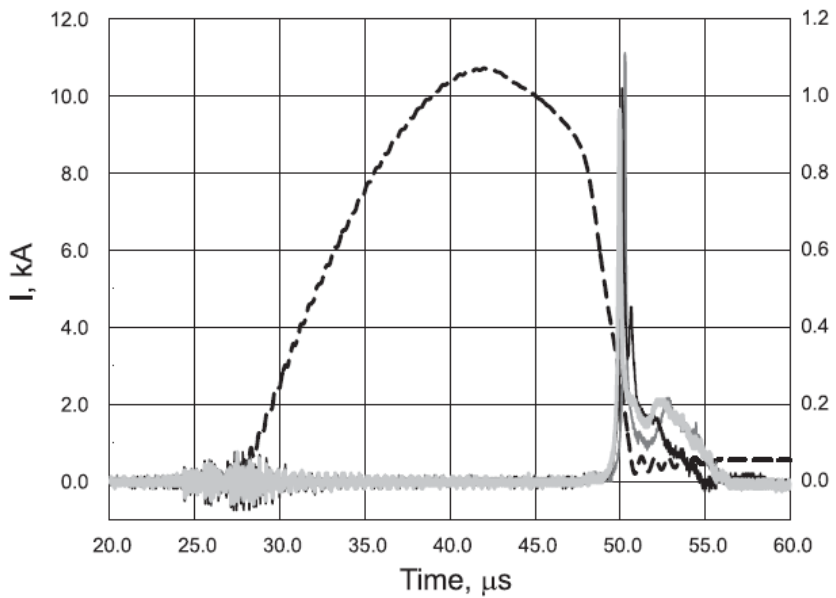


Fig. 7. Discharge current (dashed curve) and three signals from optical pins (solid curves) at copper wire explosion in B-type detonator with PETN charge



Fig. 8. Liner expanded through the failure of retarded HMX charge initiation from the axial detonator

As is seen in Fig.4, for three optical pins distant 70 mm from one another, the arrival time spread is less than 150 ns.

Step 2. Control of the simultaneity of PETN charge initiation along the effective length of the detonator. Simultaneity is controlled using optical pins, each covered with a 30 μm copper shield in a similar manner as in the observation of wire explosion at Step 1. The layout includes detonators of type B (Fig. 5) or A (Fig. 6) filled with PETN. Figure 7 shows a typical curve of time dependence of the discharge current and the signals from optical pins at the PETN charge detonation.

The arrival time spread for three optical pins is less than 150 ns for both types of detonators.

Step 3. The detonator's initiating power was tested for detonators A and B to ascertain steady initiation of the main charge.

In our experiments, we used the armature of length 412 mm and outer diameter of 41 mm with the wall thickness of 3 mm and retarded HMX charge of density 1.47 g/cm^3 . A duct in the charge is formed along the liner's axis and then sized using an extra punch to fit the outer diameter of the detonator – 12 mm. Then the detonator is placed symmetrically into the duct in such a way that it fits closely against the walls of the duct in the main explosive charge. To ensure a uniform initiation of the main charge, the gap between the detonator's surface and the main charge must be less than or equal to 0.03 mm.

The main charge initiation failure occurred in the experiment with A-type detonator (Fig. 8).

The experiment with B-type detonator gave positive results. The experiment was performed with a shorter armature of length 212 mm; the density of retarded HMX charge was 1.47 g/cm^3 . It should be noted that the detonator effective length for deto-

nator B appears less than that for detonator A, the length of the exploding wire being the same for both.

No detonator failure was observed in the experiments. All conclusions about the main charge detonation were made from the analysis of fragments and traces of the armature tube on the protective screens. The protective screens were made of 10mm steel plates and placed at the distance of 1.5 m from the charge. The fragment size, shape and penetration depth were considered.

Experiments are in progress. At the next stage, the expansion velocity for the armature tube with HMX charge initiated by B-type detonator will be measured.

Interestingly, to ensure a reliable charge initiation, the energy delivered to the exploding wire appears to be lower than that necessary for a rigorous wire explosion. Really, according to [3], the current providing wire explosion can be evaluated by the

specific action $h = \int_0^{t_d} j^2 dt$, where j is the current density and t_d is the time to explosion.

The value of the specific action depends on the wire material and is about $4.1 \cdot 10^9 \text{ A}^2 \cdot \text{s}/\text{cm}^4$ for copper ($3.1 \cdot 10^9 \text{ A}^2 \cdot \text{s}/\text{cm}^4$ from melting to explosion). In our experiments, the specific action at which successful detonation occurs in the PETN charge adjacent to the exploding wire is $h = (2.1 - 2.4) \cdot 10^9 \text{ A}^2 \cdot \text{s}/\text{cm}^4$. It should be mentioned here that it has not been proved that the obtained value of the specific action is the minimum value permitting the initiation of explosives.

A similar relation is known [4] for exploding bridgewire (EBW) detonators using a gold wire: the specific action for gold wire explosion is about $1.8 \cdot 10^9 \text{ A}^2 \cdot \text{s}/\text{cm}^4$ [3], whereas the value $0.57 \cdot 10^9 \text{ A}^2 \cdot \text{s}/\text{cm}^4$ is sufficient for EBW detonator operation [4]. This effect can be attributed to several factors, for example, detonation stimulation by discharge processes and deflagration to detonation transition. But all these phenomena fall out of the scope of the present study.

The main challenge of the suggested detonators is that wire explosion requires power supplies capable of storing large amounts of energy. To reduce the required amount of stored energy, one can use copper wires of smaller cross section or replace copper wires with aluminium or gold ones, since the specific action for aluminium (gold) wire explosion is about $1.8 \cdot 10^9 \text{ A}^2 \cdot \text{s}/\text{cm}^4$ [3]. Use of aluminium wires could probably provide additional benefits for explosive initiation in the vicinity of the exploding wire because of increasing the explosion strength due to additional heat release through aluminium burning after detonation.

Fig. 9 exemplifies the use of the suggested detonator in an FCG with axial initiation. Axially initiated detonator 1 is fitted into armature 2 installed coaxially with FCG 3. The length of the armature is such that it allows for loading extra explosive charges 5 of density $1.0 - 1.2 \text{ g}/\text{cm}^3$, thus reducing the effects of main charge 4 discharge. Outer covers 6 of the armature provide a means of preventing the explosives from spilling during the installation into the FCG. The projecting open ends of the armature are encased in sleeves 7 to prevent them from being untimely cut off along the open face ends of the flanges during the armature expansion. Leads 8 connect the detonator to a high-voltage capacitor bank.

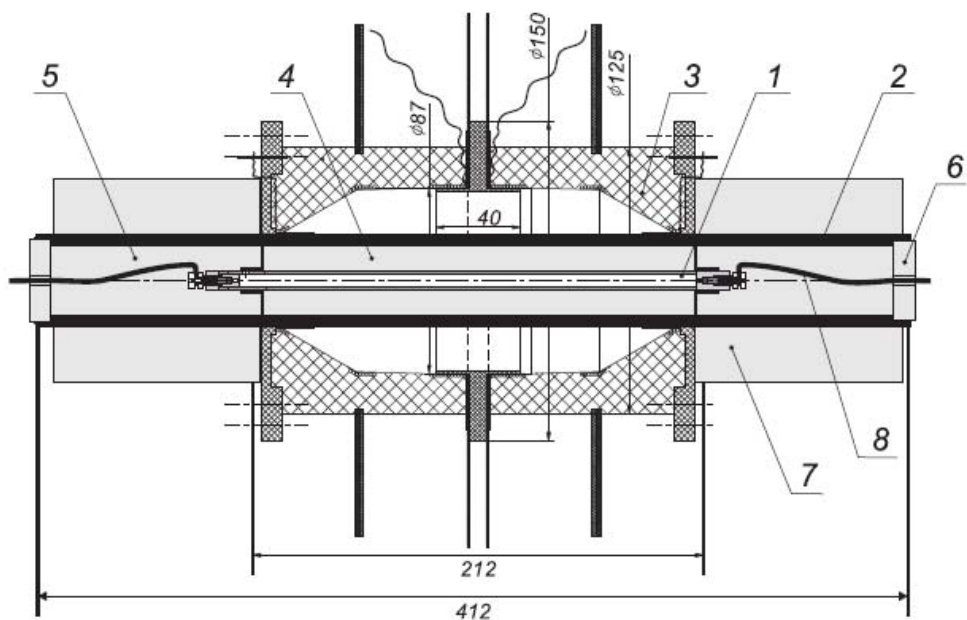


Fig. 9. Scheme of detonator installation into FCG

4. Conclusion

The experiments on the initiation of high-explosive charges by a shock wave initiation unit with a lengthy exploding wire fuse have been described. The simultaneity of initiation of the detonator charge along its length and the simultaneity of initiation of the main charge in the armature tube by a lengthy detonator have been experimentally confirmed.

References

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