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Research paper

Measurements of the Function Time of a Prototype Exploding Bridge Wire Detonator

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Abstract: Exploding Bridge Wire (EBW) detonators are essential for high-reliability, precisely timed explosive initiation in aerospace and defense systems. Their low sensitivity to external disturbances and excellent timing accuracy make them ideal for multi-point detonation, stage separation, and flight termination devices. A new EBW-based initiation system was designed around a platinum bridge-wire mounted on a PCB and pressed into a brass head. The configurations tested included bare wire, RDX initial pressing, and a high-density output pellet. The function time was measured using photodiodes and an oscilloscope, capturing voltage spikes from the post-initiation optical emissions. This setup enabled sub-microsecond time resolution across multiple trials, necessary for the preliminary qualification of a new device type. The function time for the bare wire averaged 3.23 µs (30 samples), with a jitter of 69 ns. Initial pressing detonation showed a wider time range with a mean of 37 µs (7 tests). With an output pellet, the mean function time was 9.8 µs (5 tests), exhibiting low variability and reliable detonation. The photodiode reading was highest for high-output configurations, where products of detonation exposed light emission out of the brass head violently. This EBW system demonstrated excellent performance across all configurations. The experimental results confirm its readiness for integration into flight and warhead systems requiring precise timing.

Keywords: exploding bridge-wire, initiating device, detonator, function time

1 Introduction

The Exploding Bridge Wire (EBW) initiating device was invented in the early 1940's as a part of the highly classified Manhattan project [1], marking its first use in nuclear applications. The EBW concept emerged to solve the problem of achieving simultaneous multi-point initiation without relying on the traditional, more variable chemical fuses or impact-sensitive components. EBW technology has since evolved and proliferated into a broad array of applications, both military and civilian. In modern times, EBWs are routinely used in missile systems, warhead arming mechanisms, aerospace vehicle separation devices, and even spacecraft payload deployment systems, but also in areas such as mining, construction and explosive welding. Their insensitivity to electrostatic discharge, combined with the ability to remain dormant and safe until electrically triggered, makes them a vital tool for any system where timing accuracy, reliability, and safety are non-negotiable requirements. Compared to conventional initiation systems, such as blasting caps or pyrotechnic primers, EBWs offer significant advantages. Traditional devices rely on heat, flame, or mechanical impact to initiate explosives, which introduces unwanted variability in timing, greater sensitivity to external disturbances, and safety risks during storage and transport.

An exploding bridge-wire initiating device works thanks to the rapid plasma-generating evaporization of a low resistance thin wire. Beforehand, a small capacitor is charged to a high voltage. A switch and transmission line then allows the current to burst the wire bridge. This mechanism leads to the formation of a "hot-spot" in the initial pressing material, which then creates a detonation in a booster or main charge. Initial pressing is a lightly pressed around the wire portion of explosive, which tends to exhibit higher sensitivity to initiation. In non-military applications, the "explosive effect" was used in the production of nanoparticles [2]. There is actual uncertainty about how exactly the energy transfer occurs and the initiation begins, which has been discussed by Rae and Dickson [3] and further investigated in detail by others [4]. However extensive experimental works over the years has produced many reliable products, which have been applied in civil and military industries.

Critical for the testing of a detonator is the function time (t_f), which is the time delay between the initiation signal and early wall movement [5]. A typical value is in the range of microseconds. Jitter recorded for simultaneity is in the range of tens of nanoseconds [6] for the detonators manufactured with class "A" equipment. It is a crucial parameter for safety, quality and resultant operability, and is especially needed for ensuring simultaneity in applications involving multi-point initiation, where differential delays – even of the order of tens of nanoseconds – can result in unacceptable asymmetries in energy delivery. In missile and spacecraft applications, precise synchronization of separation charges or warhead triggers can directly impact mission success or failure.

EBW operation and purpose is similar in nature to the exploding foil initiator (EFI) device type, where the foil accelerates the high velocity flyer or 'slapper' instead of the initial pressing, which in turn impacts a secondary explosive. Although the present work focuses primarily on EBW initiators, references to EFIs are also included where appropriate, due to the similar underlying physics of energy deposition, Joule heating, and shock-driven initiation. EFIs often provide complementary data or experimental insights, particularly in areas such as timing, circuit insights and the mentioned multi-point initiation [7].

A universal EBW-based initiation device coupled with an adjustable explosive amount was recently developed in our Institute to allow missile designers to tailor the device to multiple purposes where pyrotechnical action is necessary. Figure 1 illustrates the developed EBW detonator used for measurements. Currently it is constructed to fit into a compact ø7 mm head. It is going to be used for flight termination explosive main charge initiation, pyrotechnical release devices for stage separation and future work on smart warheads. In these time critical applications, there is a need to assess the performance of the whole firing system. The application is tailored to be an all–secondary explosive detonator, with no interrupter needed in the explosive train, which means practically that it has to pass all the safety tests of MIL-STD and STANAG, with the qualified explosives for in-line assembly.

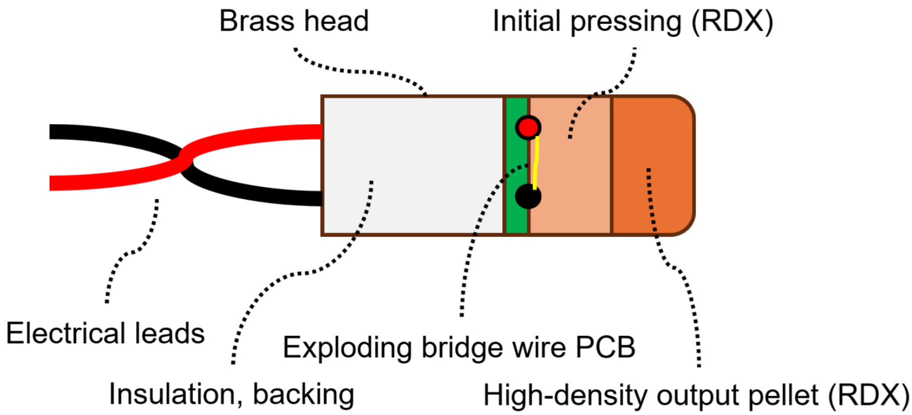

Figure 1. The developed explosive bridge-wire detonator scheme

The scientific contribution of this work is twofold: it provides a reproducible, locally manufacturable testbed that enables systematic study, which can be used for precise armament development, and it supplies baseline experimental data for the key performance metrics of EBW initiation, that can be developed from market available components, with minimal special production. This ensures that the production of the device is to be cost efficient. The most critical parameters to evaluate and report in EBW research are listed below. They determine timing stability, energy coupling to the bridge, and practical repeatability of the initiation event. Although constant experimental work is being done it often lack the function time determination and statistics of the whole assembly [8], which is crucial for time critical applications. Characterising these parameters quantitatively (with uncertainty estimates) enables comparison between designs, and focused follow-up studies that aim to reduce variability and increase reliability in production phase. A method of testing was proposed with critical review.

2 The Device

The operating logic of the developed initiating circuit is based on the controlled charging of the capacitor to a suitable voltage and the subsequent rapid transfer of energy to the pyrotechnic element. The logical protection system consists of power-handling electronics in the loop that only initiate charging of the capacitor after an authorization command has been issued. The initiation of the energy transfer takes place after the safety conditions have been passed on all threads of the control logic processors. There is a physical electric interlock to block the function of the device prior to activation and an acceleration sensor for a successful missile takeoff detection. The protection is therefore multi-stage.

The firing circuit is presented schematically in Figure 2, and consists of:

– voltage multiplier, which is powered only after safe and arm logical conditions are met,
– high-voltage capacitor, *C*, which is charged accordingly, converting the supplied energy into a short, high-power pulse,
– gas-filled switches, which acts as physical triggers between non-conducting state and firing, allowing for a capacitor discharge,
– series inductor, L_0, which is experimentally chosen, to shape current pulse rise time flowing into EBW,
– series resistance, R_0, which represents resistive loss in the loop, representing the leads and wire,
– bleed resistor, R_B, which discharges the residual charge in non armed state and while the charged device is to be set to disarmed, acting as a safety element.

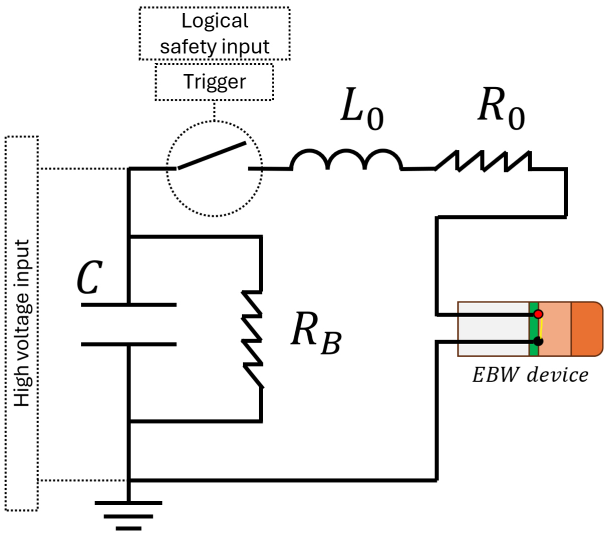

Figure 2. Initiation circuit scheme for this EBW device

This set-up manages the generation of the proper rate of current rise for the initiating pulse generation in the wire. The initiator is enclosed in a brass head. It has a PCB based platinum explosive bridge wire, connected to two electrical leads. The bridge-wire is in direct contact with the initial pressing of low-density 1,3,5-trinitroperhydro-1,3,5-triazine (RDX) and the high-density output pellet, which when necessary is pressed to a higher percentage of the theoretical maximal density from fine RDX. Most of the EBWs manufactured and tested historically and commercially available contain 2,2-bis[(nitrooxy) methyl]propane-1,3-diyl dinitrate (PETN) as the initiating explosive. PETN is good enough with a minimal firing current of 200 A for most cases and is widely available at different grain sizes. RDX has a higher firing current of 450 A and is frequently used where higher operating temperatures are required [9]. Its use is not widely described in the literature, although people indicated its feasibility. In missiles it has one more important advantage of being not sensitive to vibrations stimulating flight in opposition to PETN [10]. This was found to be vital for externally located pyrobolts for missiles and was used for the present work. Military grade EBW's often use hexanitrostilbene (HNS), which is superior in terms of temperature stability.

3 Test Method

It was required to capture the blast wave front in a sub-microsecond physically imposed regime. In such high-speed events, conventional instrumentation often lacks the necessary bandwidth or temporal resolution. An analysis ofpublicly available literature on examining detail of the exact moment of bridge-wire explosion indicated thata high speed optical camera, and X-ray and proton radiography are found to provide a powerful visualization for reexamining the technology [11]. Measurements can be made using pressure transducers, especially piezoelectric ones [12]. Most of the experimental work on the function time of EBWs is based on optical measurements, which can be done by custom-made fiber optic probes [13].

For the present study, a combination of optical sensing and electronic triggering methods was employed to capture the relevant initiation dynamics. Several other diagnostic tools were considered, including the above mentioned high-speed imaging and fiber-optic probes, which are feasible. Among these, photodiode-based detection was selected as the primary method due to its high temporal resolution, ease of integration, and minimal system overheads for repeatable experimental campaigns. Photodiodes, particularly those with fast response times and sensitivity in the near-infrared spectrum, are highly suitable for detecting the optical flash emitted during the detonation event. These devices, when properly positioned, can detect radiative signatures associated with plasma formation or explosive reaction fronts. The emission, though transient, provides a clear and trackable voltage spike when captured with a suitable high-bandwidth oscilloscope.

The experimental campaign was structured into three distinct stages, each targeting a different configuration of the EBW detonator:

– firstly, to estimate the lag in the power system, the time from the firing signal to the exposed (not embedded in explosive material) bridge-wire explosion was acquired. Ultimately, it was not subtracted from the loaded head results.
– consecutive measurements will assess the 120 ±2 mg of RDX initial pressing dynamics, with no output pellet. Such a prepared head has 13 mm of length. The goal was to evaluate whether the output radiation and wall displacement could be consistently detected and how the density of the pellet potentially corresponds to the mechanisms observed in this device. It also allowed assessment of the variability in energy transfer, particularly in cases where the pressing material may undergo deformation before rupture.
– finally, the last set of 250 ±2 mg of a high-density RDX output pellet is pressed with 250 ±2 mg of initial pressing with the wire embedded. This configuration has a head length of 21 mm. This configuration represents a realistic application scenario, where the EBW must initiate an explosive train strong enough to propagate through the output charge and into a target medium. The aim was to determine the shortest, most consistent function time under full-load conditions.

4 Test Setup

A photodiode (PD) is placed in-line with the exposed exploding bridge-wire, with no head, for quantification of the circuit lag. This was done in the laboratory using a PicoScope 5444D oscilloscope and Osram SFH203P photodiodes, which can capture a 400-1100 nm wavelength band. The sampling rate of the oscilloscope was set to 500 MS/s for both input channels.Exactly the same hardware was used for the field-deployed measurements. The PD was put into a short thin-walled plastic tube. At the end of the tube there was the cylindrical wall of EBW head, which had a direct line of sight to the emission zone. This was done to eliminate ambient inclusions. The detonator was enclosed by a steel tube to retain the fragments and debris. Whole assembly was enclosed in a shadowed box. This exact scheme is presented on Figure 3.

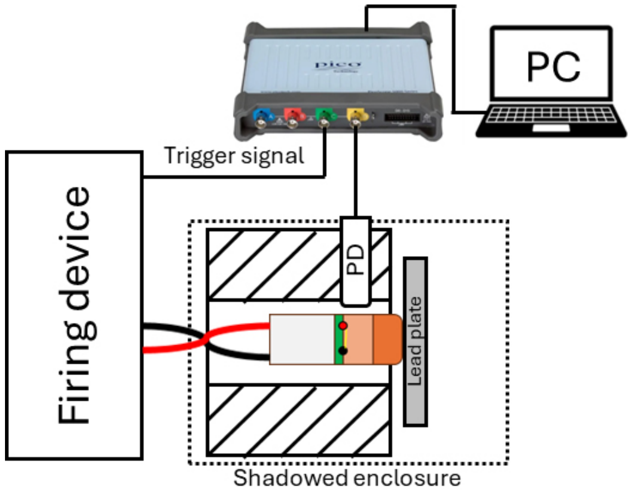

Figure 3. Test setup scheme

To synchronize the photodiode readings with the ignition event, the firing signal from the power electronics was used as the trigger reference. This signal, upon reaching the switch, initiates the capacitor discharge into the bridge-wire circuit. The precise measurement of the time gap between the leading edge of the firing signal and the onset of the photodiode response forms the basis for calculating the function time.

The detonator itself is glued to a lead witness plate in order to assess a coarse but immediately visual confirmation of detonation. It is an early "go" or "no-go" determination method. Initial pressings should only dent the plate, but with an output pellet it is penetrated. The head of the EBW device was perpendicularly bonded to the lead plate. It is worth noting that the RDX detonation velocity is 8700 m/s [14], which determines the negligibility of a spacing between PD and detonating EBW on function time.

5 Results

The resulting reading output was post-processed and presented. Figure 4 shows the signal reading plotted for an exposed bridge wire explosion. While evidently occurring, no electromagnetic interference was found to be an issue for initiation, but one has to be cautious about the functionality of neighbouring equipment. The "function time" for the bare wire was taken as the difference from a 10%

rise of the trigger signal from zero on Channel 1 of the oscilloscope to 50% rise time of the PD voltage reading on Channel 2, which corresponds to the read peak reading difference of roughly 1.5 V.

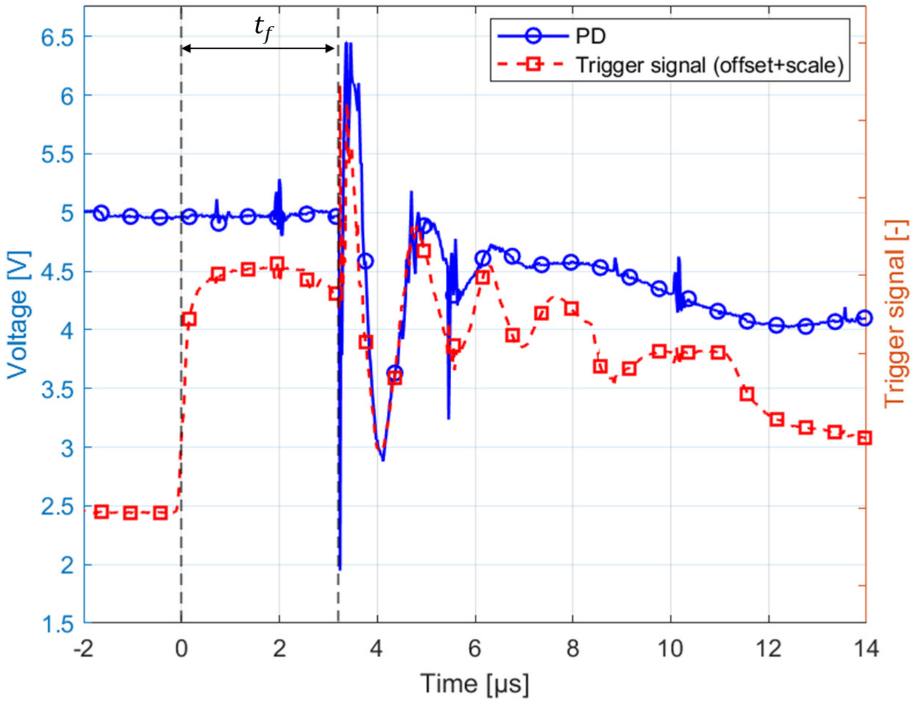

Figure 4. Typical signals for an exposed EBW *versus* function time

5.1 Bare exploding bridge-wire

This configuration was tested with 30 shots. Figure 5 shows the histogram with a Gaussian fit for the tested pieces. The mean function time was 3.23 μs. The resulting standard deviation of these results (jitter) was measured to be 69 ns, which is 2.1% of the mean value.

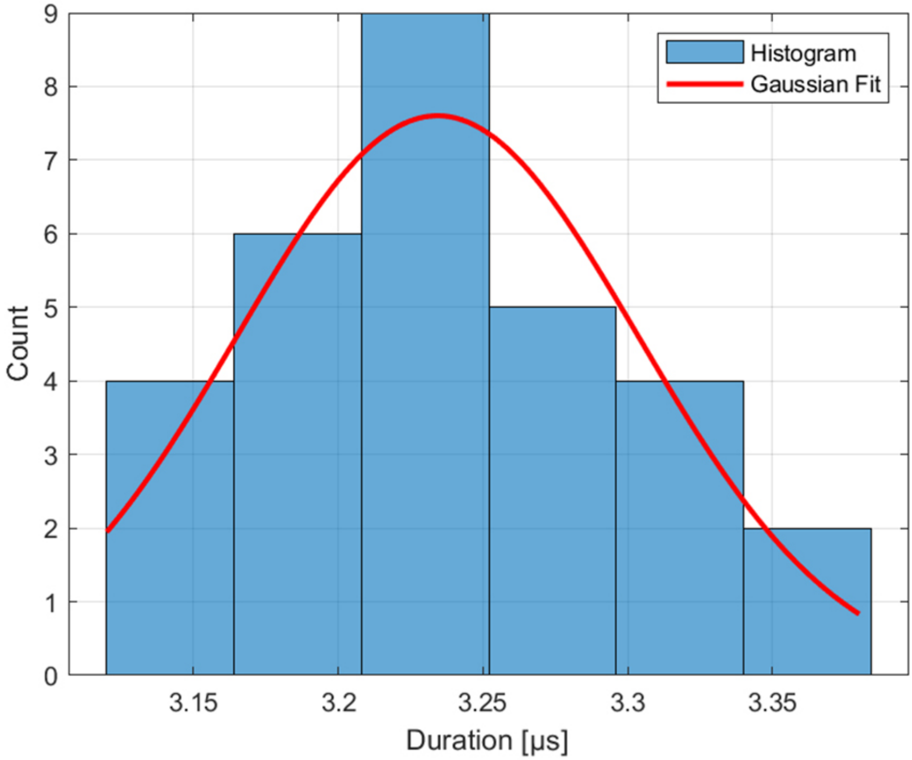

Figure 5. Histogram for EBW initiation

5.2 Initial pressing detonation

Exactly the same measurement setup was employed for the initial pressing detonation initiated by the EBW. In the current series, the device was pressed into a designed brass head. A total of 7 shots were conducted, all of which were valid. The results demonstrated consistent repeatability, with no duds. A PD was placed 50 mm from the device. The PD signal captured the early visible emission and peaked at around 850 nm, which is the maximal sensitivity. Early wall movement was measured at a mean function time of 37 μs, but the range was from 18 to 56 μs. This is possibly due to the fact that a low velocity detonation induced input pressing that was not powerful enough to break the head. It is believed that the extended in time elastic bulging and therefore late exposure of the physics to the conducting element was the issue. This can be especially seen on the E and G readings presented in Figure 6. Peak-to-peak difference measurement of PD signal was close to 5 V. The PDs were changed after every shot, but they remained healthy overall due to the weak effects.

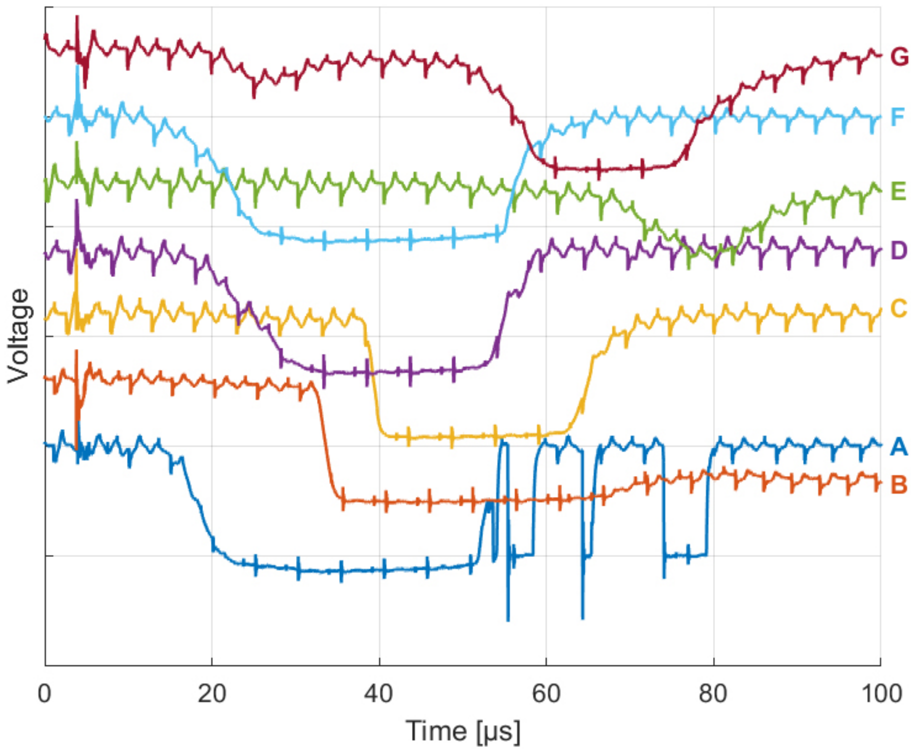

Figure 6. Stacked and smoothed signal voltage from the PD (initial pressing only configuration)

5.3 Output pellet detonation

Total of 5 shots were tested and the reading of PD signal are shown in Figure 7. All were of "go" type. They produced a mean reading of 9.8 μs for early movement, with a range from 9.2 to 10.5 μs. This suggests that the detonation reaction occurred, since the effect was more abrupt then in the case of the initial pressing only. The maximal sensitivity was reached after 20-25 μs. Post-peak signal fluctuations were disregarded. The results here are more consistent than for the initial pressing only and peak-to-peak difference measurement of PD signal was in the 5 V, which means that the limit of possible to measure light intensity was already reached with the mass of initial pressing detonation.

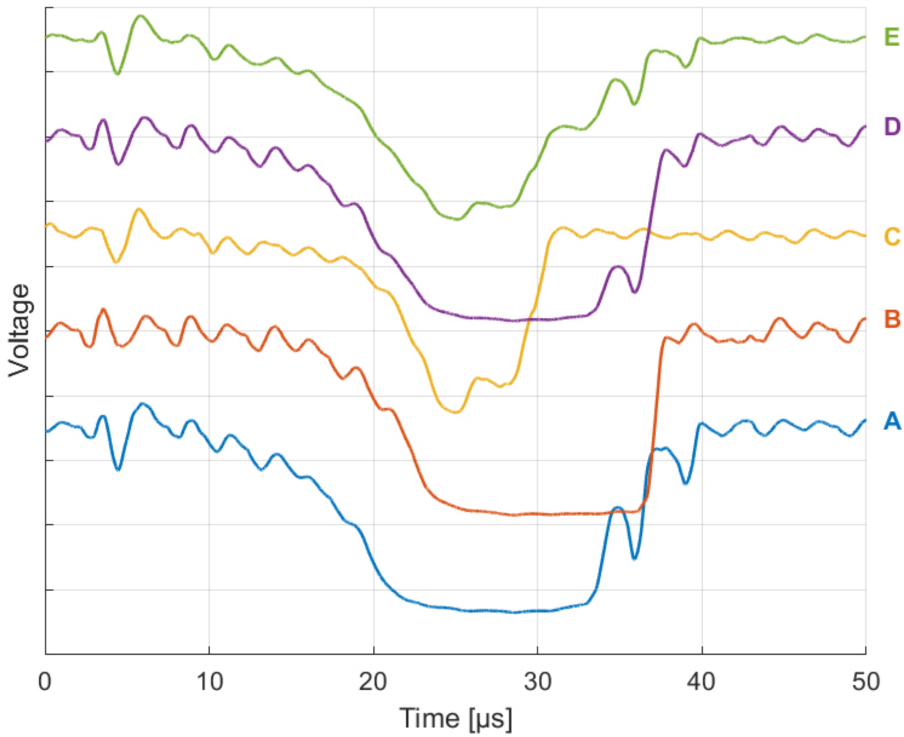

Figure 7. Stacked and smoothed signal voltage from the PD (initial pressing and output pellet configuration)

6 Discussion

The photodiode method and the hardware used provided valuable insights about the repeatability and functionality, but lacked sensitivity for some cases. The metal head was found to absorb too much energy before releasing a measurable emission. Hence, the method was not optimal for this configuration, because of material elasticity involved with chosen metal head. A more convenient way of elaboration for testing using this method would be in a brittle polymer, which would not hold the explosion light emissivity for an unforeseeable amount of time. Although the test samples were low in number, it has shown that the PD method exhibits good reproducibility, when the detonator is fired with a higher mass load of RDX. One point worth noting is that the source of resulting jitter may be partially due to the poor initial prototype manufacturing methods, and process tuning is ongoing.

What is more, the device was additionally tested and successfully used to trigger detonation of a 0.6 kg Comp-B main charge with a casted RDX booster. This was a part of qualification in post-laboratory validation in a real scenario of use. The fact matters, because it proves that the detonator does not deflagrate and can sustain explosive chain, which is part of its development. All the components used are market available, hence ready for production.

7 Conclusions

- A laboratory stand was developed and results were presented to assess the performance and quality of a prototype series of EBWs and detonator. A function time was found to be:
  - bare break-wire explosion: 3.23 ±0.18 µs (n = 30),
  - initial pressing EBW initiator: 37 ±19 µs (n = 7),
  - output pellet detonation: 9.8 ±0.07 µs (n = 5).

  These results are consistent with the literature and values reported by commercial specifications.
- Repeatability across units, with higher sample weight demonstrated that material and technology assesses is ready for qualification and testing for the pre-production phase.
- The prototype power electronics module is capable of sufficient rise-time generation in order to impose the shock on RDX-based systems, which is believed to be more stable than the widely used PETN. Therefore it may exhibit slightly delayed activation profiles.

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Authorship contribution statement

Maciej Krzysztof Cichocki:	foundations, methods, performing the statistical analysis, other contribution to the publication
Dariusz Sokołowski:	conception
Michał Pyza:	performing the experimental part

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