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# On peculiarities of near-threshold initiation of powder density explosive by air shock wave and by solid impactor

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**Abstract.** The features of near-threshold mode of initiating by gas-tight piston and high-enthalpy gas flow was evaluated for a powder density explosive PETN. Both methods lead to the development of detonation in about 10  $\mu$ s time. The synchrotron radiation diagnostics have shown that the initial stages of the process were significantly different, that diversity being caused by the influence of the gas flow in the pores of the charge. In this work, the effect of the gas flow on the mode of initiation was studied experimentally.

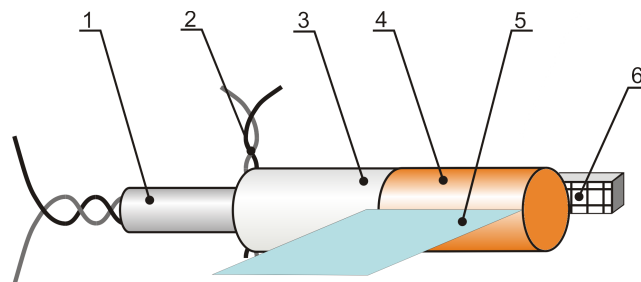
## 1. Introduction

There are two basic methods of detonation initiation in high explosives (HEs). The impact of the shock wave of sufficient amplitude leads to the development of the detonation in a microsecond time interval, or even less. However, this method requires a strong action of some impactor, usually accelerated by the pressure of detonation products. The most common case of shock initiator is conventional detonator. To initiate detonation in the base charge, first you need to arrange the same process in the detonator, typically using sensitive, and therefore dangerous primary explosives.

The second way of initiation is deflagration to detonation transition (DDT). This comparatively slow process may take milliseconds. In contrast to the shock initiation, the initial pulse may be rather weak. Typical HE ignited at the initial normal conditions burns slowly, but the gradual increase of pressure leads to acceleration of reaction rate. Now, fast (hundreds m/s) convective combustion eventually develops in the permeable for gaseous products charge – the hot gases penetrate into the pores of fresh explosive and ignite new portions of material. Rapid gas emission causes the compression of the HE, and finally the detonation wave develops with further pressure rise. Obviously, such process is possible when HE is confined in a shell, for example, in a strong metal tube. DDT is relatively less determined process, what is natural at longer time needed.

In our works [1, 2, 3, 4], the different way to initiate detonation was studied in detail, which can be regarded as an intermediate between the two classical methods described above, and which, to certain extent, combines their advantages. This is the impact of high enthalpy gas flow with the powdered HE. There are several ways to create a flow with the required parameters—the





**Figure 1.** The experimental scheme. 1 – generator of the initiating flow, 2 – contact sensor, 3 – air gap, 4 – sample, 5 – SR beam, 6 – detector of passed radiation.

electric explosion of wires, breakthrough of the combustion products from a separate chamber, gas detonation, etc. [5, 6, 7]. In the blasting practice, high enthalpy flow occurs when the detonation is transmitted through the air gap. At given sufficient flow intensity, the detonation develops within the  $10 \mu\text{s}$  time range. This is fast enough to discard the requirement of the strong casing since inertial confinement is sufficient enough. As a result, the initiation can be realized in size of standard detonators.

Physical prerequisite for the high enthalpy initiation is quite intense activation of explosive powder by the hot gas flow. As a result, the rapid convective burning develops in the charge immediately, thus the slow layer-to-layer combustion stage which is the weak link of standard DDT is avoided.

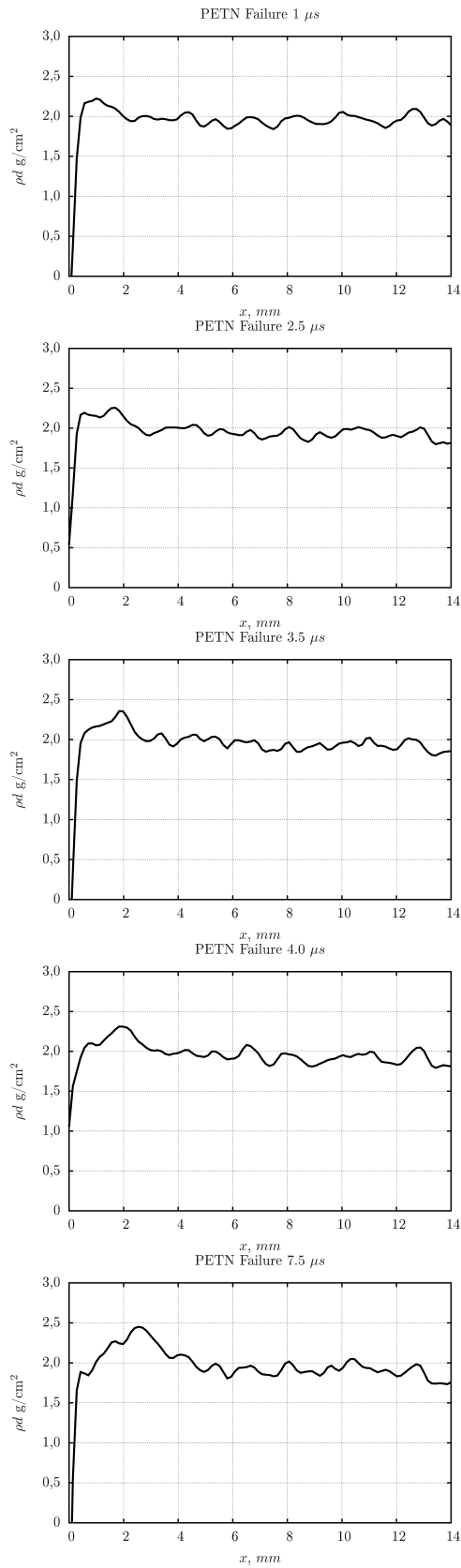
In this study, three variants of impulse action on powder PETN are compared experimentally:

- near-critical high-enthalpy initiation which leads to successful development of detonation;
- subcritical, weaker impact of the gas flow, which results in a failure;
- the impact by the metal plate.

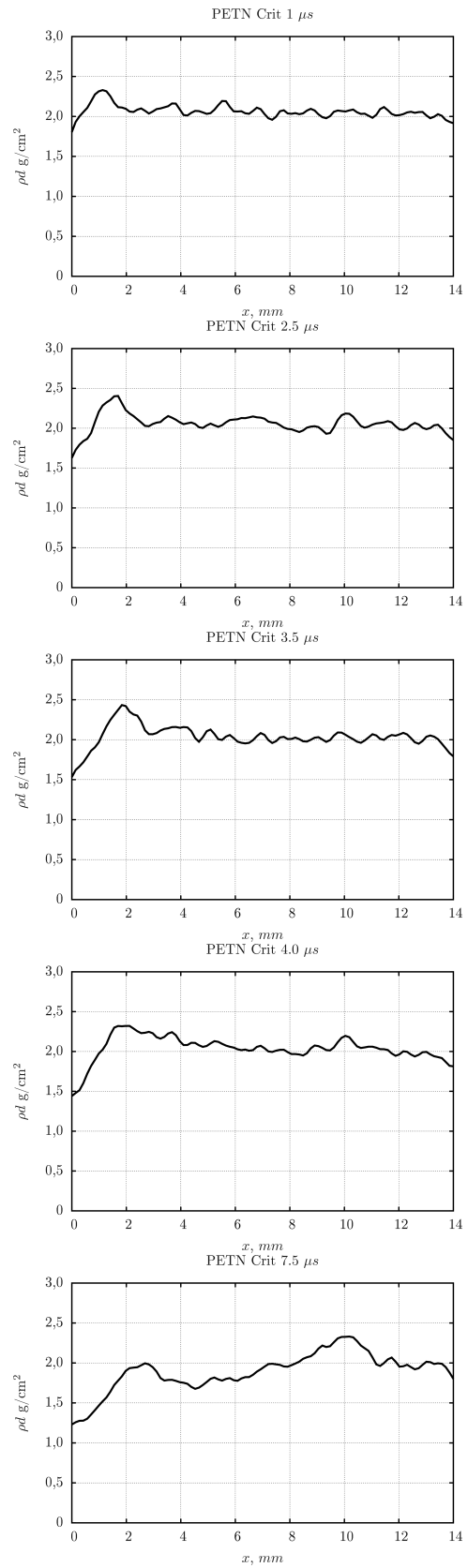
We found that the detonation occurs under conditions of moderate compression of powder PETN, whereas in the case of failure the compression is much higher. The reason of this paradox is the rapid reaction with appreciable generation of the gas phase in the case of successful initiation, which reduces the compressibility of the material. As a result, the powdered explosive remains permeable for the gas, and the detonation develops through two-phase flow stage. On the contrary, in the case of failure, the gas generation due to chemical reaction inside the charge is insignificant. Thus, the explosive is easily compressed similarly to an inert powder of comparable mechanical properties. Pores in the charge are closed and convective combustion has no chance to penetrate into the layers of undisturbed material.

## 2. Experiment

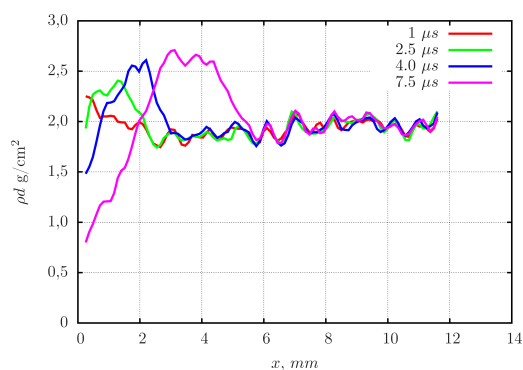
The processes within the explosive sample were studied using the synchrotron radiation (SR) diagnostics [8, 9] which provides a shadow slit X-ray film with spatial resolution down to 0.1 mm and the time interval between frames is  $0.496 \mu\text{s}$ . Thus, it was possible to trace the initiation from the stage of undisturbed state of the material to the development of the detonation. Calibration of measuring equipment allowed us to convert the beam attenuation data into the quantity of mass along the beamline (measured in  $\text{g}/\text{cm}^2$ ). This is simply the product of density and the sample diameter for uniform one-dimensional axisymmetric case. The real flow is not uniform and essentially two dimensional which complicates recovering of the density distribution. However, in our case, the direct qualitative data on the evolution of the quantity of mass along the beamline during the first microseconds of the process were found to be informative enough.



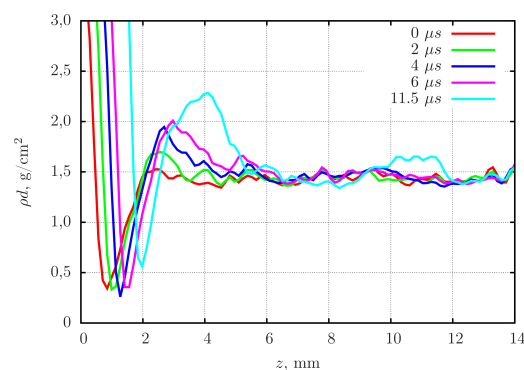
**Figure 2.** Failure, subcritical regime. The speed of the air shock wave is 2.4 km/s.



**Figure 3.** Near-critical regime. The speed of the air shock wave is 2.6 km/s.



**Figure 4.** Impact of high enthalpy flow on the inert powder.



**Figure 5.** Initiation of powder density PETN by Al impactor.

The scheme of experiments is shown in figure 1. The explosive generator of the initiating flow (1) produced the hot gas behind the air shock. The same primary charge closed the contact sensor (2) for the synchronization of the measuring equipment. The air gap (3) was adjusted to regulate the flow parameters. The flat SR beam (5) is directed onto the test sample (4). Passed radiation is registered by the linear detector (6).

Near-critical regime of initiation PETN charge of powder density by high-enthalpy gas flow occurred if the velocity of the incident air shock wave was 2.6 km/s. If the air shock velocity was reduced to 2.4 km/s, the detonation was not registered during the observation time that was more than 10  $\mu$ s. We also compared the experimental data on HE with the results obtained for inert powder (sugar) of similar density and dispersity.

The dynamics of the mass on the beamline for the case of failure in which the hot gas impact does not produce detonation is shown in figure 2. Figure 3 shows the data for the near-critical initiation regime. One may note that during the start of both processes the behaviour of samples was almost identical. The discrepancies begin at approximately fourth microsecond from the moment of impact. In the case of the successful initiation the compression of the charge slows down and acceleration of the wave front was observed which further develops into the detonation wave. For the case of failure, the radiographed mass continues to increase to greater level than that achieved with more intensive impact, without any disturbances propagating ahead of the compressed region. The velocity of compression wave was significantly slower than in the case of near-critical initiation.

Clearly, the discrepancies in the development of the process are the manifestation of the reaction induced at the surface of explosive grains in the case of a successful detonation. The influence of the gas produced in the reaction on the movement of the condensed phase becomes visible after about 4 microseconds.

The results for the more intensive impact on the inert powder are shown in figure 4. One can note more rapid formation of a dense region without any disturbances ahead of the main wave front. The dynamics of the process at an early stage is similar to powdered charge initiation by solid impactor (figure 5), 2 mm thick aluminium plate, details see in [4]. Here the charge was initiated by compression wave instead of penetration of hot gases. The absence of reaction on the particle's surfaces leads to formation of the thick compressed region. In this case, the reaction starts at the front of the compression wave and propagates into the undisturbed explosive, with eventual transition to detonation, while the region of compressed explosive remains inert.

### 3. Conclusions

Impact of high-enthalpy gas flow with the porous charges lead to quite different results depending on its intensity. If the hot gas flow is too weak to initiate the fast combustion of the condensed phase, then a powder is compacted into a dense plug near the charge interface. This plug blocks the gases from penetrating into the main charge. In general, such a process is similar to initiation by solid impactor. On the contrary, more intense gas flow filtering into the pores leads to ignition of explosive particles. The gas produced in the reaction prevents the further compression of the material, so the porous bed retains its permeability. Moreover, the reaction gases filtrate into the explosive in the initial state producing the convective combustion wave. The visible difference in the wave dynamics was observed at 4  $\mu$ s from the start of the process. This gives an upper bound for the PETN ignition time in a near-threshold regime. Actually, the ignition occurs much earlier since the gas produced in the reaction needs time to affect the movement of dense solid phase. To conclude, the effect of gas released in the combustion process is crucial.

It was found recently that in coarse grained loose packed explosives even the developed detonation wave may depend upon the convective processes [10]. We would like to underline that these convective mechanism appeared to be most important in particular for PETN, studied in the present paper. Thus, there exists a possibility of the common nature of accelerating wave in PETN, from the start of the high enthalpy initiation process to the final “normal” detonation regime.

### Acknowledgments

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