Detonation of Highly Porous Explosives

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According to Zeldovich – von Neumann – Döring theory [1], the detonation wave is a complex consisting of leading shock, chemical reaction zone, sonic Chapman – Jouguet surface and finally an expansion wave. This model, for its classical simplicity and clarity, was widely accepted well before any experimental confirmations.

Nevertheless there exist systems for which ZND model seems hardly suitable. For low density explosives (0.2 – 0.8 g/cm^3), prepared by distribution of explosive grains in a foam plastic, convective propagation mechanism prevails [2]. It is quite natural that shock stimulation meets difficulties without direct contact between the individual grains and jets of the reaction products suggested by Apin [3] become more effective propagation agent.

At the natural filling density the grains are in contact with each other but volume fraction of empty space is still substantial (about 40%), and the jets of reaction products still may propagate through the pores. Results of Dremin et al. dating from 1960s [4] were in general agreement with the ZND model. However the time resolution available at that time (around 100 ns) is not adequate today because it is comparable with or larger than the characteristic detonation reaction time.

There exist several observations pointing to the importance of convective propagation mechanism in loose packed explosives [5,6]. Furthermore, recently [7] we studied low density PETN, RDX and HMX using the VISAR diagnostics. In coarse grained materials two different detonation regimes were registered. One was the standard ZND profile with distinct von Neumann peak, but in several experiments sharp flow pulsations were observed which does not agree with the ZND paradigm.

In the present work the same explosives were explored using the electromagnetic method. The time resolution was about 5 ns. As in [7], the sensor was protected by the epoxy layer 50 – 100 μm thick. The working arm of the electromagnetic gauge was around 1 mm long, i.e., comparable with the grain size, and the effective gauge area was close to that of VISAR spot. Thus direct comparison with the VISAR data [7] was possible. Again mostly von Neumann peaks were found but violent chaotic pulsations were observed in several cases.

Numerical analysis of the gauge response to the non-uniform flow was performed. The action of the explosive products on the window material was simulated using an acoustic approximation, assuming that different spots of the interface start to move at different time moments, the typical spread being $\tau = \Delta/D$, here Δ is grain size and D is detonation velocity. For typical Δ = 300 μm and D = 5 μm/ns $\tau \approx 60$ ns. We found that gauge dimensions play an important role. Point sensors (i.e., those much smaller than Δ) react not only to the nearest non-uniformity, but to fairly remote parts of the moving interface as well and register high amplitude oscillations for quite a long time after the velocity at the interface becomes uniform (retardation effect). For large sensors the output signal is averaged, and the sensor area of $4\Delta^2$ is enough to suppress this unwanted noise. The averaged VISAR velocity is fairly close to the electromagnetic one, though the level of oscillations is slightly higher, due to nonlinearity of the VISAR converting procedure. Thus VISAR method turned out to be quite robust which was hard to expect from a subtle interferometric technique.

The actual gauges were large enough, so the oscillations registered in the experiments were not artefacts but they reflect real processes within the detonation wave. The results indicate that both shock driven and convective wave can propagate in loose packed explosive. Apparently for the same charge, in different parts of the wave front either shock or jets can dominate as a leading process, depending on the details of the local placement of the grains.

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