DETONATION FRONT STRUCTURE IN LOW DENSITY EXPLOSIVES

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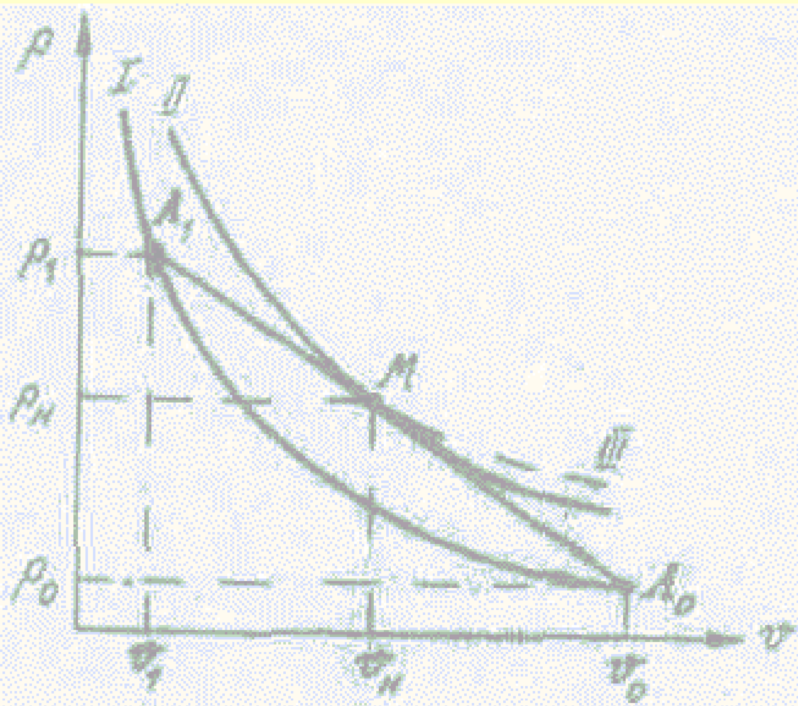
Central dogma of detonation

Shock wave ignites the reaction
(Zeldovich – von Neumann – Doering model, ≈1940).
Von Neumann spike is expected



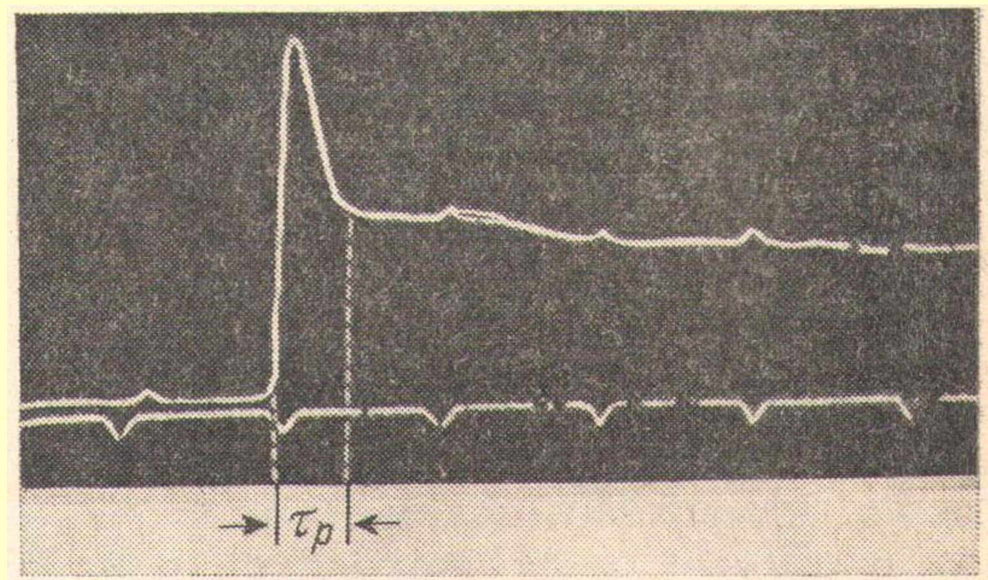
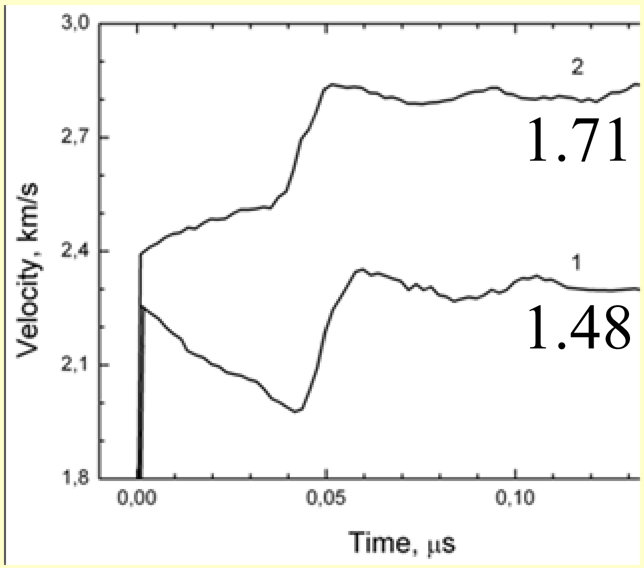


Рис. 8.30. Типичная осциллограмма регистрации массовой скорости в детонационной волне.

ZND theory, being an outstanding intellectual achievement, was accepted well before any experimental confirmation

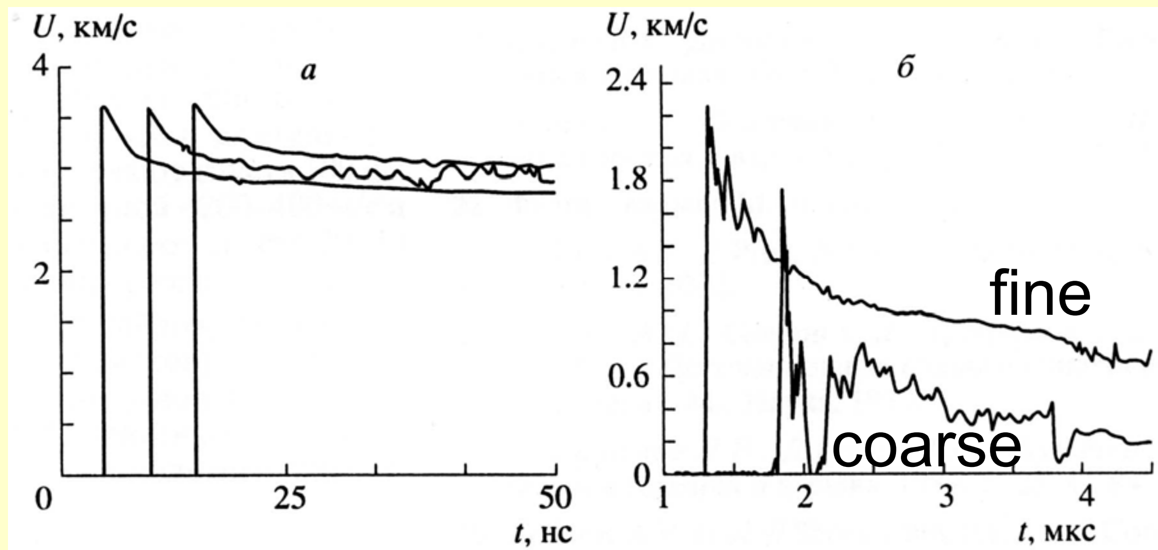
Experiment: deviations do happen

TNETB



PBX 1.83-1.84

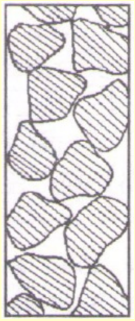
HMX 1.24



A.V. Utkin et al., 2006

R.L. Gustavsen et al. 1998

Low density explosives



The idea of leading shock becomes vague in loose packed explosives.

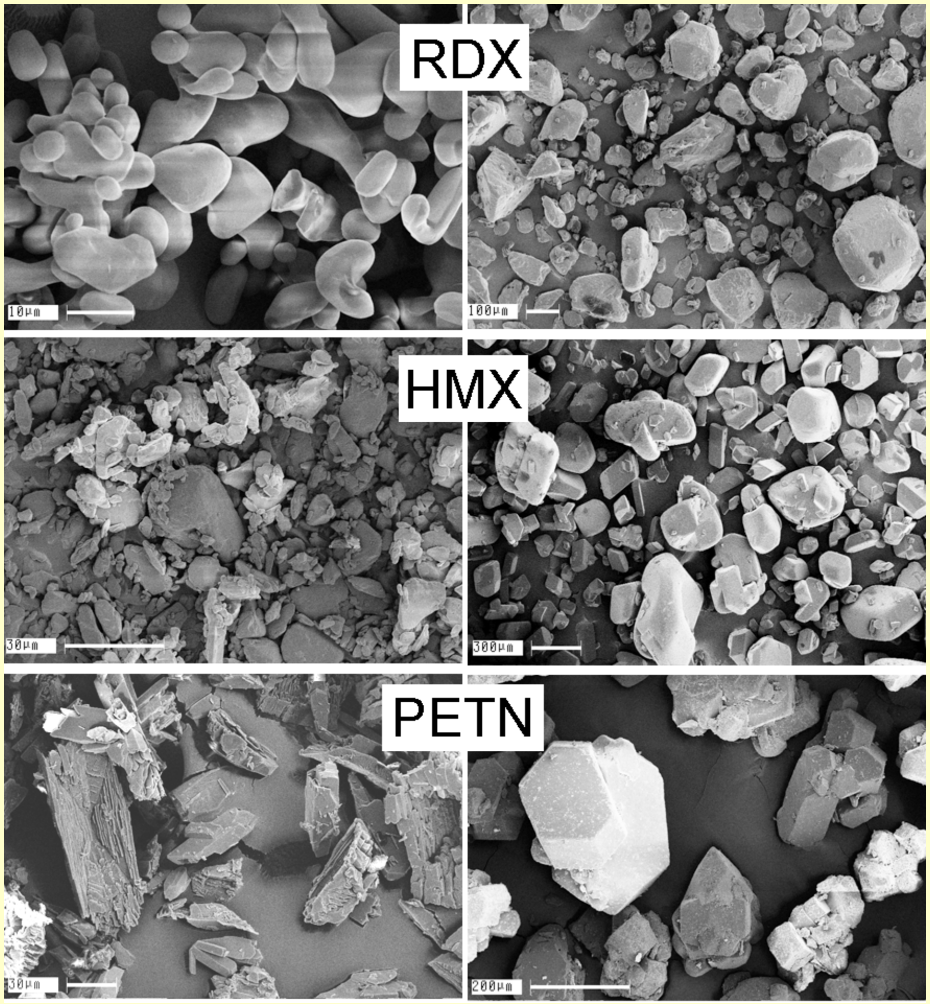
Low density explosives are promising medium for convective, or jet propagation mechanism, as suggested by A. Ya. Apin (1946)

At very low densities, below 0.5 and down to 0.001 g/cc, the jet mechanism was confirmed by V.S. Soloviev et al. (1977), V.V. Mitrofanov et al. (1980), A.V. Pinaev (1992).

For natural low density packing ~ 1 g/cc mainly old data of A.N. Dremin et al. are available (around 1970, ZND?), of rather poor resolution of ~ 100 ns. DDT propagated by jets was found by L.A. Lukyanchikov et al. (1974…)

A question: Is ZND valid at low densities?

Electrical conductivity in low density explosives. Role of the grain size



11 μm 10↔

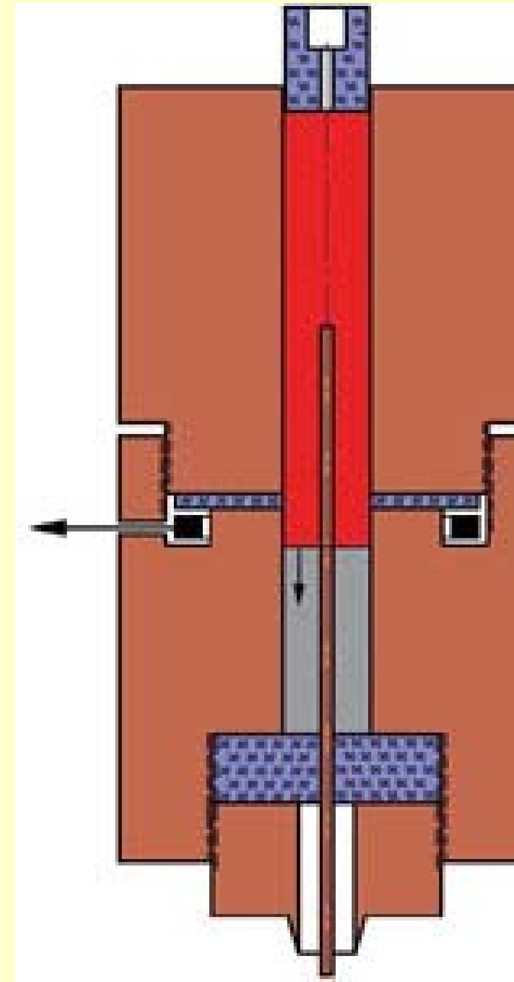
160 μm ↔100

21 μm 30↔

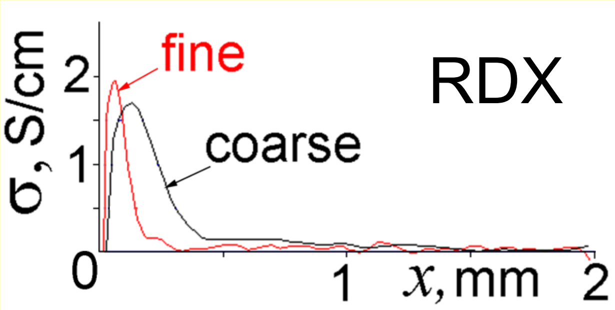
430 μm ↔300

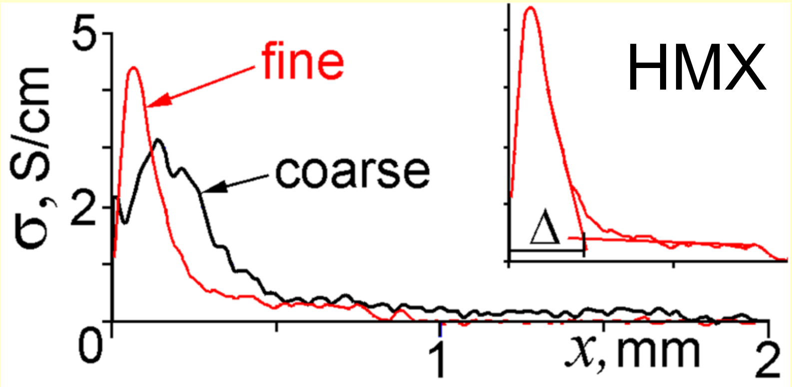
80 μm 30↔

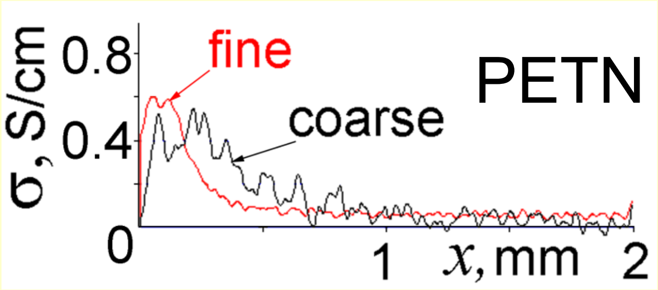
260 μm ↔200



Conductivity: results







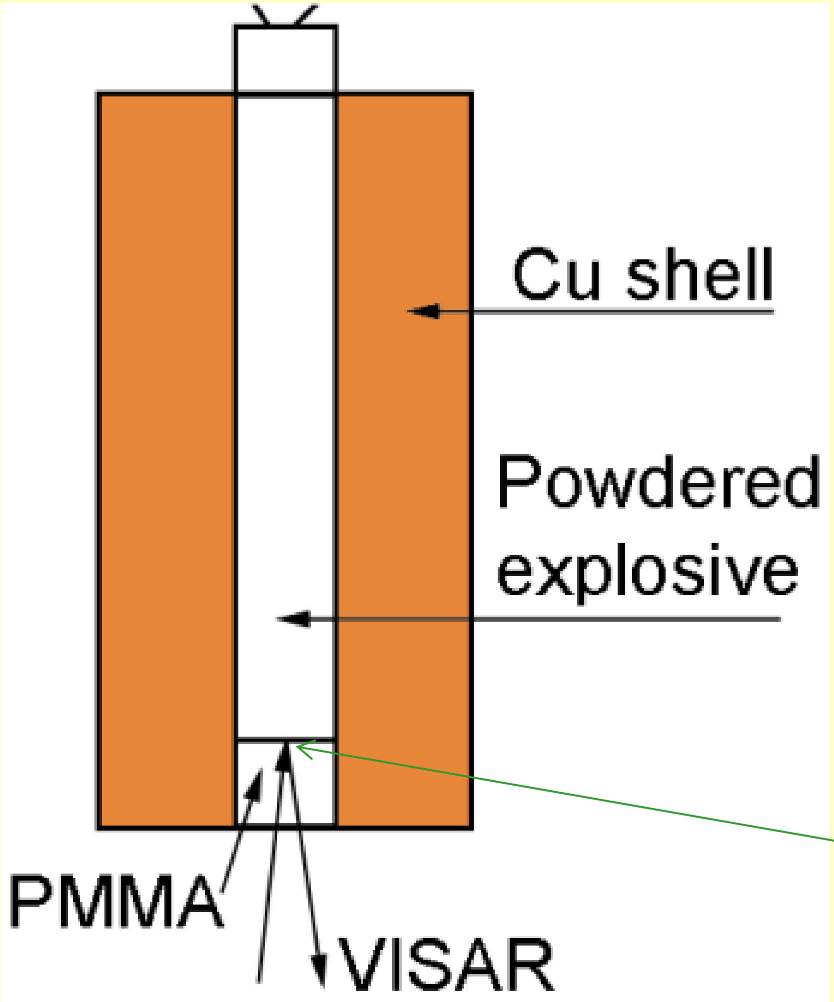
18 shots, 3 explosives:
3 fine and 3 coarse each

“Fine” σ peaks are about two times shorter.
“Coarse” profiles are noisy.

A.P. Ershov, N.P. Satonkina. Combustion & Flame, **157**, no.5, 1022-1026 (2010)

VISAR EXPERIMENTS

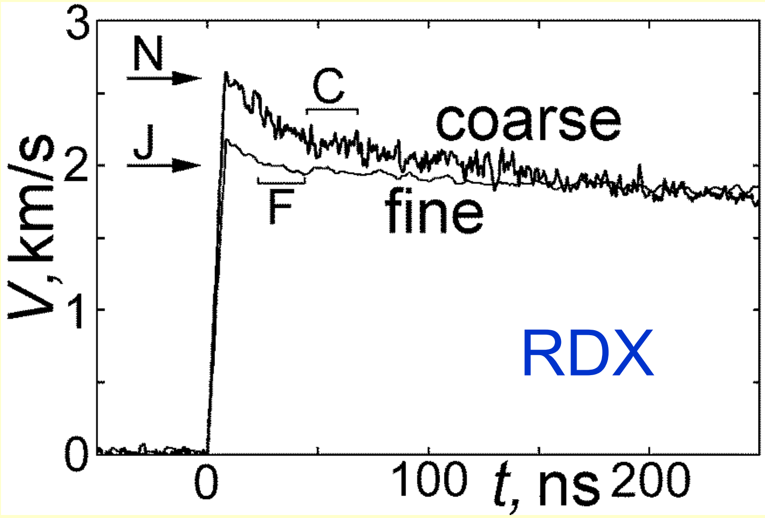
Natural next step: conventional flow measurements under the same conditions

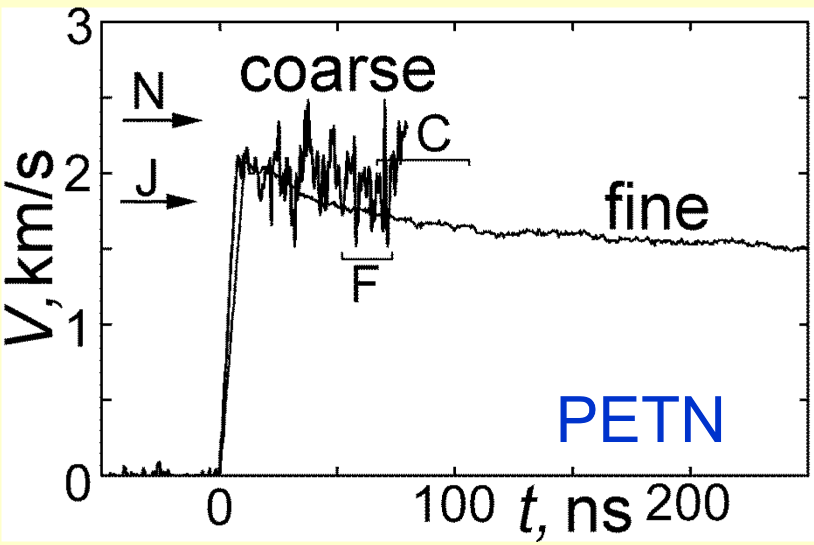


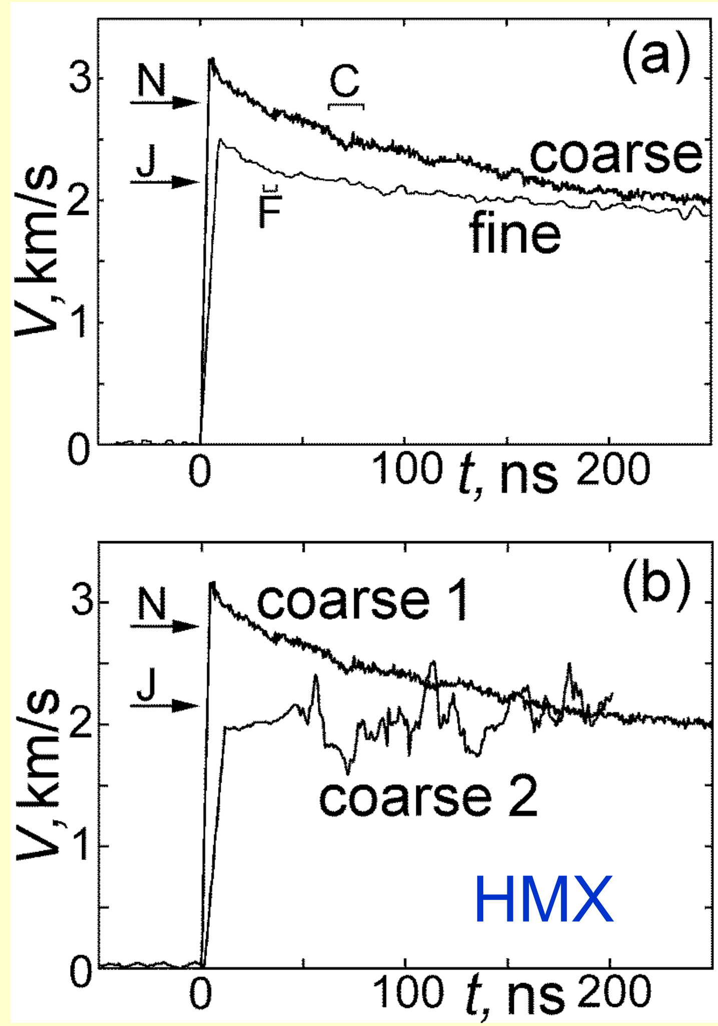
RDX, HMX, PETN: the same products

Al foil 7 μm thick, protected by ~ 100 μm epoxy layer

VISAR data



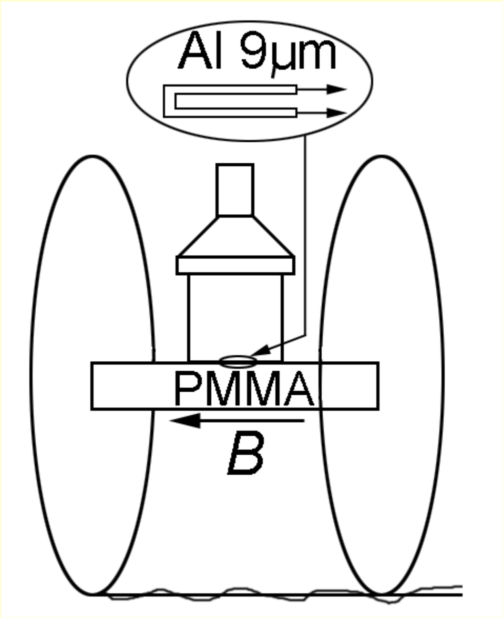




ZND profiles in fine-grained, noisy or non-ZND in coarse-grained. A.P. Ershov et al., JAP 119, 075903 (2016).

ELECTRO MAGNETIC EXPERIMENTS

Submillimeter grains → small gauges → small charges



Helmholtz coil

3 kV, 1 kA

Ø 12 cm

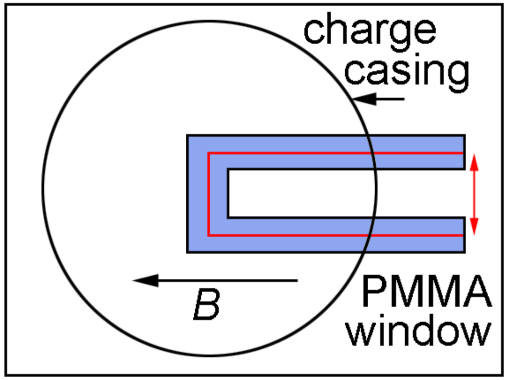
2 x 10 turns

B = 0.15 T

Charge

Ø 18 mm

h 25 mm



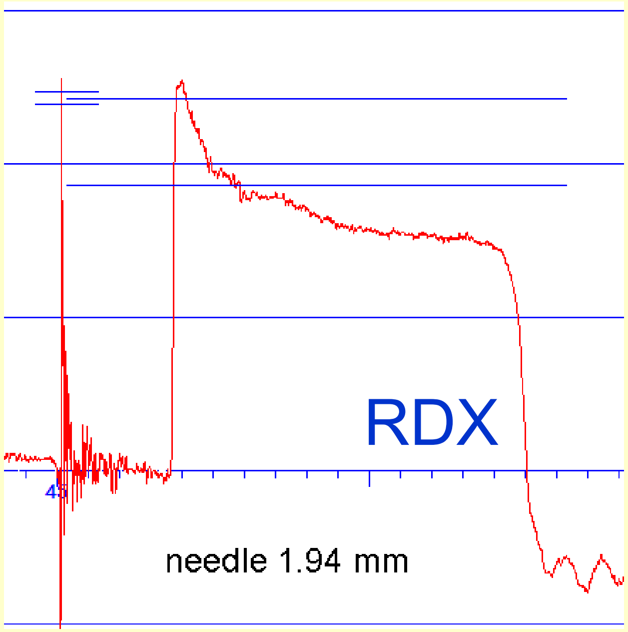
Gauge glued on PMMA

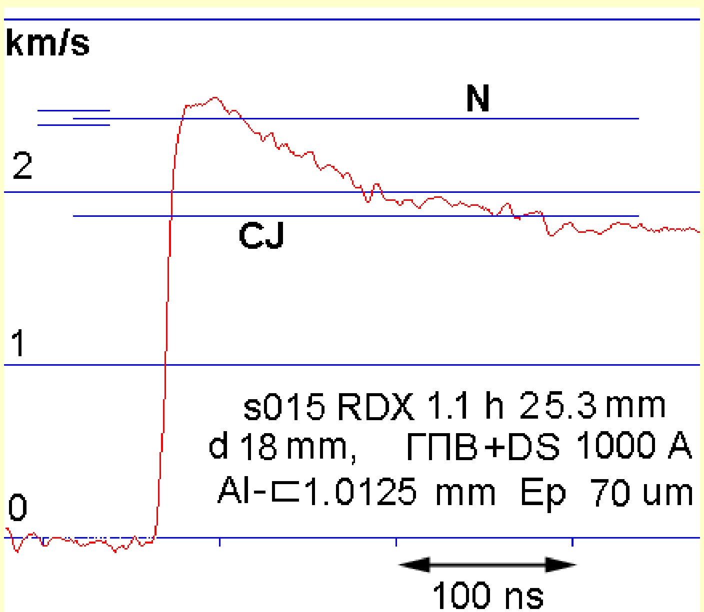
Effective width ≈ 1 mm

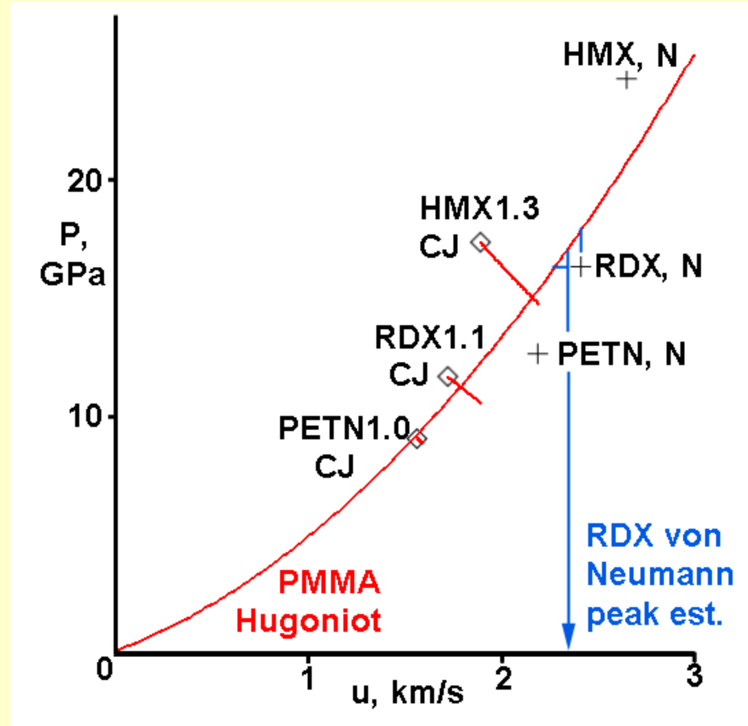
U ≈ 0.3 V (for 2 km/s)

Gauge covered by 50 – 100 μm epoxy layer, noise grounded by ≈ 0.6 mm Al needle

Electro magnetic data

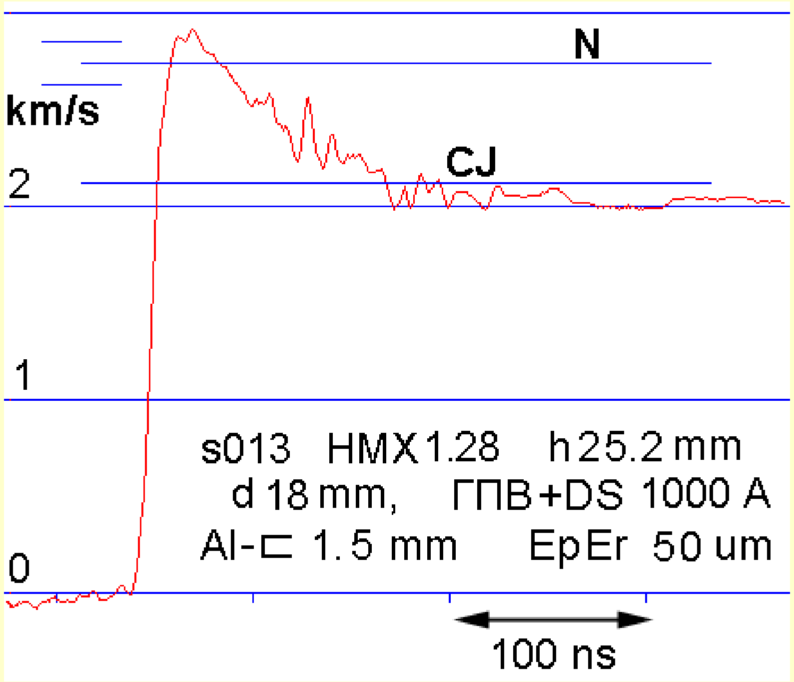


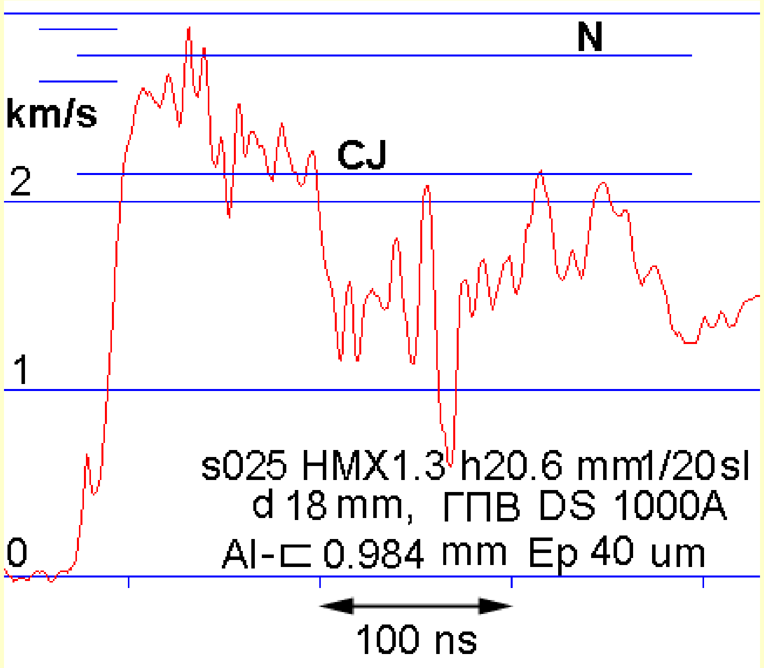




Coarse RDX (160 µm)
Good ZND

Electro magnetic data

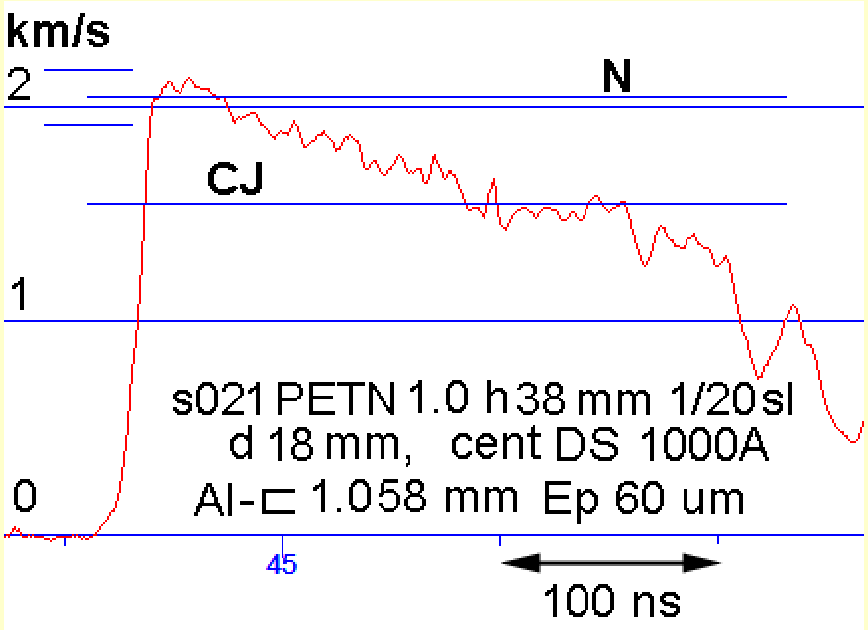


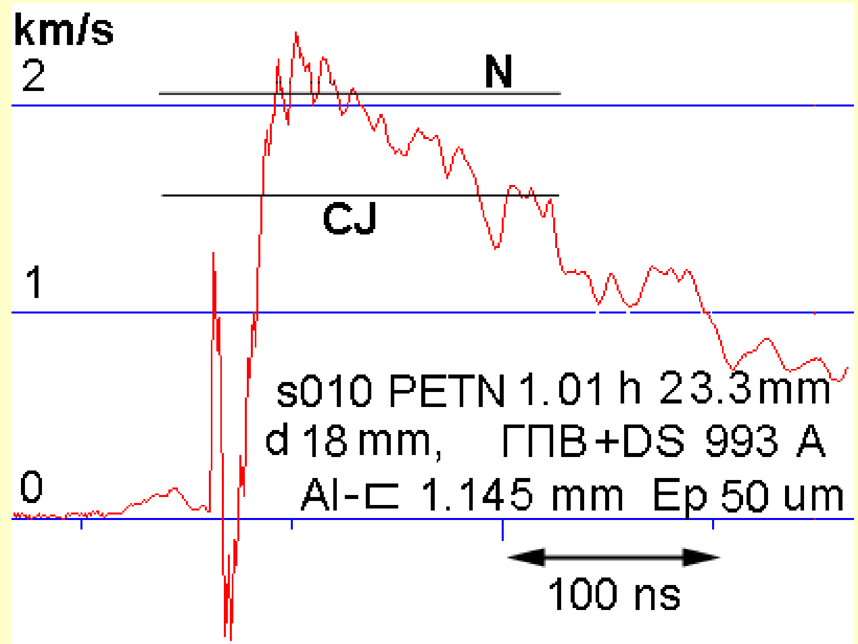


Good ↑ ZND? ↑ Doubtful

Coarse HMX (430 μm)

Electro magnetic data





Good ↑ ZND ↑ Noisy

Coarse PETN (260 μm)

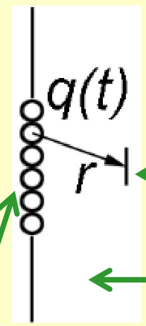
EXPERIMENTS: SUMMARY

Classical ZND profiles were observed in fine-grained explosives. In coarse RDX (160 μm) von Neumann peak was also present, with more amount of noise, apparently due to flow pulsations.

In most coarse HMX (430 μm) either the spike or chaotic pulsations of the velocity can be found.

In PETN (260 μm) electromagnetic measurements gave the spike (sometimes noisy), but the VISAR demonstrated mighty noise. This difference can be attributed to the lower stability of the VISAR procedure.

Acoustic analysis of EM data



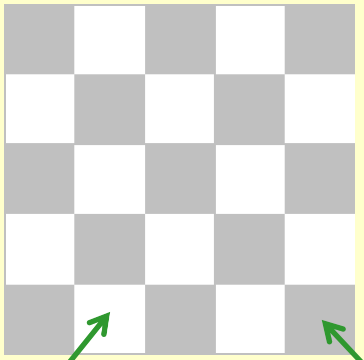
gauge

epoxy

Sources (explosive gases)

$$\varphi = -\frac{1}{2\pi}\int \frac{u(t-{}^{r}/_{c})}{r}\mathrm{ds}$$

$$p = -\rho\frac{\partial\varphi}{\partial t} \qquad u = \frac{\partial\varphi}{\partial x}$$



Grains:

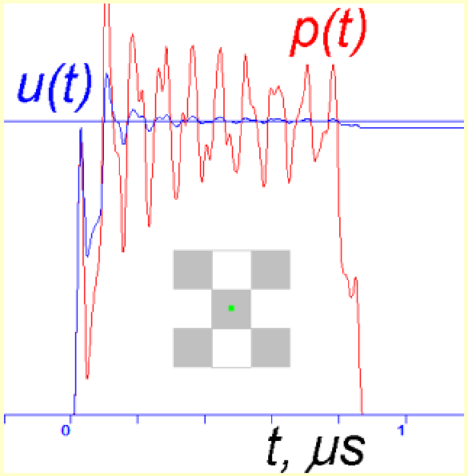
Δ

300 μm

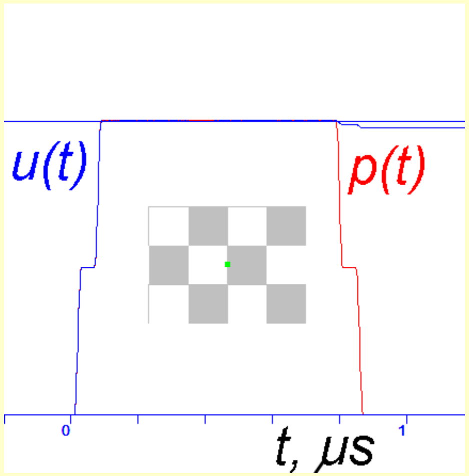
$u = \theta(t - \Delta/c)$ $\quad u = \theta(t)$

Point-like gauge, << Δ

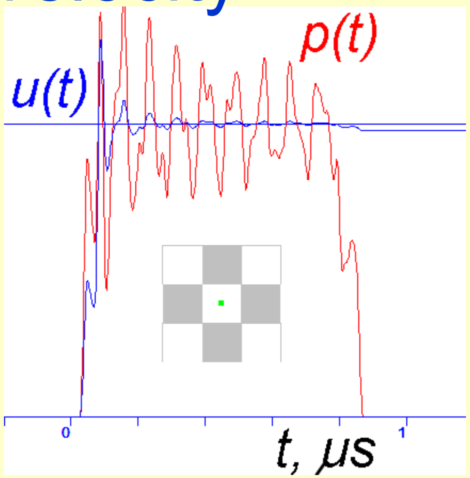
Pressure is more volatile than velocity



advanced



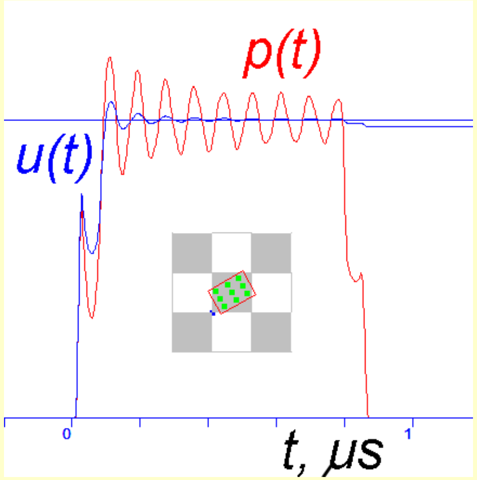
middle



retarded

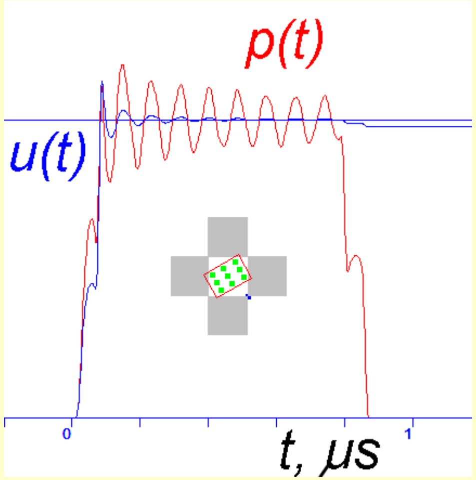
Acoustic analysis of EM data

Averaged data: 9 points (small gauge, ≈ Δ)

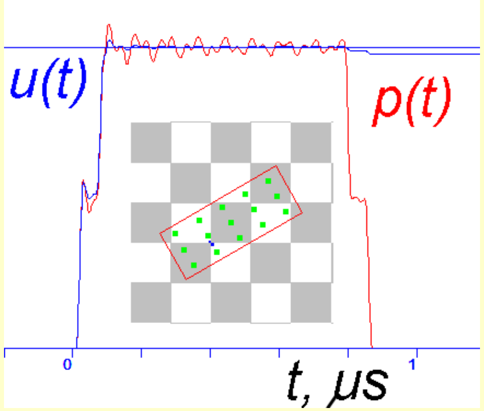


advanced

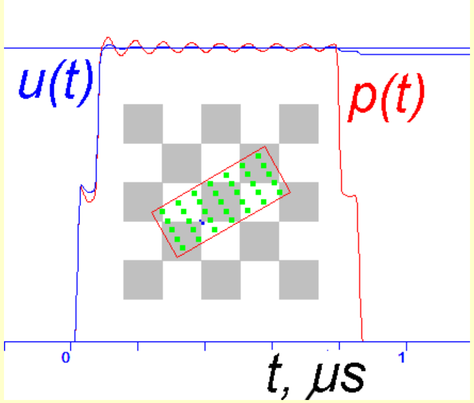
retarded



Averaged data: 15 or 35 points (real gauge, > Δ)



EM velocity does not feel the grains: quite robust method



CONCLUSIONS

The profiles observed in coarse low density packings probably indicate non-shock propagation mode, e.g. convective jet mechanism proposed by A.Ya. Apin.

In fine grained explosives the jets are suppressed and classical ZND mechanism works, though partial reaction within the compression front is possible.

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Thank you for attention