Detonation Initiation by Charges of Intermediate Symmetry

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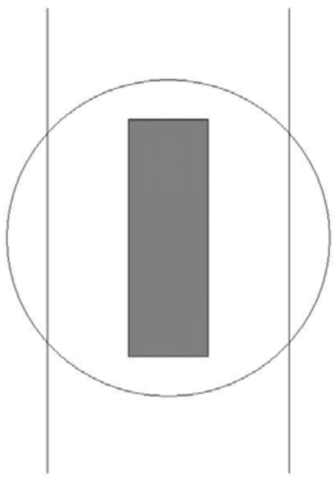
1 Introduction

It is well known the classical types of symmetry of ideal initiators – point, linear and plane. Also, it is important to know the basic relations among the spatial-time characteristics of energy-release of real initiator and the spatial-time characteristics of combustible mixture for determination of correct values of critical initiation energy and its optimisation.

As a rule, any real initiator with some characteristic dimensions may be classified from point of view of classical symmetry only approximately. For example, what type of symmetry has the thin cylindrical charge of limited diameter *d* and length *L* (fig.1) – cylindrical? Or point at $d \approx L$? Another case – plane charge of rectangular form of sizes *L*x*l*: plane, cylindrical or point at different ratio *L*/*l*? How the form of real initiator influence on initiation process and its symmetry?

The critical initiation energy by ideal initiators (ν=1,2,3 – plane, cylindrical, spherical accordingly) is illustrated on fig.2 (for charge with unit dimension) in dependence of initial pressure for mixture 2H2+O2 (similar tendencies are typical for another combustible mixtures). It is seen, that



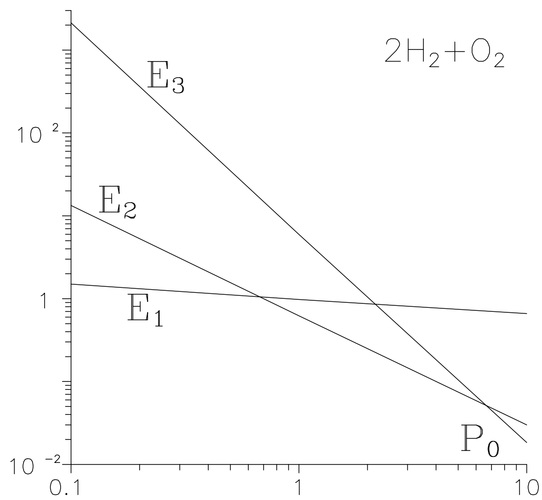


Fig.1. Schema of charge of intermediate symmetry and boundaries of DW formation at critical initiation.

Fig.2. Dependences of critical initiation energy on initial pressure for charges of ideal symmetries.

an optimisation of DW initiation at different initial pressure of explosive mixture can be achieved by changing of charge symmetry: at low pressure the initiation by plane charges is the most effective (minimal initiation energy), at high pressure – the point initiation produces the higher efficiency. So, for correct experimental determination of critical initiation energy and its optimisation it is required to know not only the spatial-time characteristics of initiators and the spatial-time characteristics of explosive mixture, but also the type of symmetry of real initiator.

2 Experimental Details

The traditional methods of initiation of cylindrical (exploding wire, linear charge of high explosive, high-speed bullet,…) and spherical (point electrical discharge, HE charge,…) detonation wave were used and their results were analyzed. The typical smoked imprints of initiation process of cylindrical detonation wave (DW) are illustrated on fig.3.

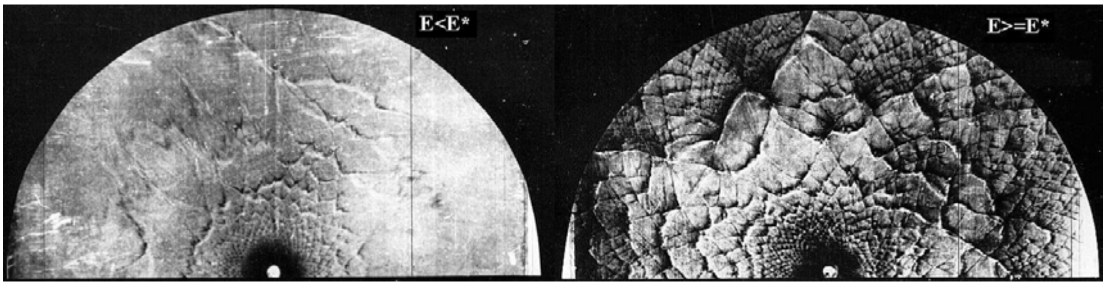


Fig.3. The smoked imprints of subcritical (left, $E<E^*$) and critical (right, $E\approx E^*$) DW initiation with the help of exploding wire.

The greater part of experiments with intermediate symmetry of initiator were performed with the help of diffraction method of DW initiation: tube of great diameter *d* and half-space volume were separated by thin membranes with orifices of different form (circle, square, triangle, rectangular,...). Such orifice plays role of initiation charge, the symmetry of which depends on orifice form (for example, at transformation of spherical initiation to cylindrical – Fig.4).

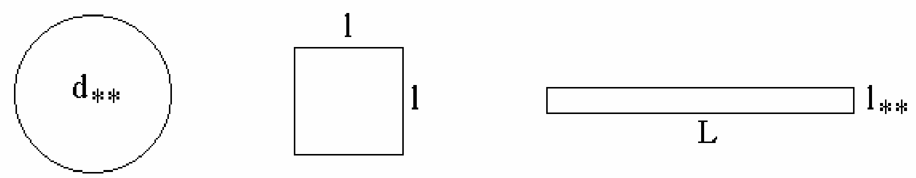


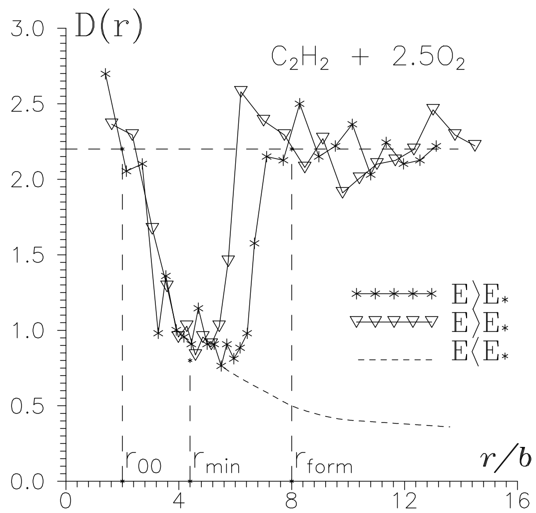
Fig.4. Schema of simplest transformation of charge symmetry: the round orifice of diameter d_{**} ensures the spherical initiation in a mixture volume, and a rectangular orifice with dimensions Lxl at $L>>l$ ensures the cylindrical initiation at $l>l_{**}$.

The experiments performed using stoichiometric mixtures of acetylene, hydrogen, and propane–butane with oxygen ("pure" and argon-diluted). The conditions for reinitiation of a multifront DW were examined at fixed geometry for various mixture pressures P_0. The pressure, at which the reinitiation and the damping of a DW were recorded with equal probability, was named as the critical pressure P_*.

The results of previous investigations of DW initiation with the help of electric discharge, exploding wire, high explosive, high-velocity bullet, a.o. were examined also from point of view of their symmetry type.

3 Some Results

The type of symmetry of real initiator must be defined with taking into account the main peculiarities of initiation process (Fig.1) and first of all the existence of the characteristic distance of DW forming r_{form} at critical regime of DW initiation ($E \approx E_*$) and the characteristic distance r_{min}, where bifurcational character of wave velocity is observed: attenuation or acceleration. On Fig.5 the experimental wave velocity on distance (wave radius r divided on the cell length *b*) is illustrated for un-successful (dotted curve) and successful DW initiation (solid lines with symbols). The basic points are marked as r_{min} and r_{form}, point r_{00} corresponds to wave velocity equals to the Chapman-Jouguet value. The values of r_{min} and r_{form} are individual for each type of symmetry. On fig.1 the schematic location of boundary of r_{form} (or r_{min}) for spherical (circle) and cylindrical (vertical lines as boundary of cylindrical surface) initiation is presented as example.



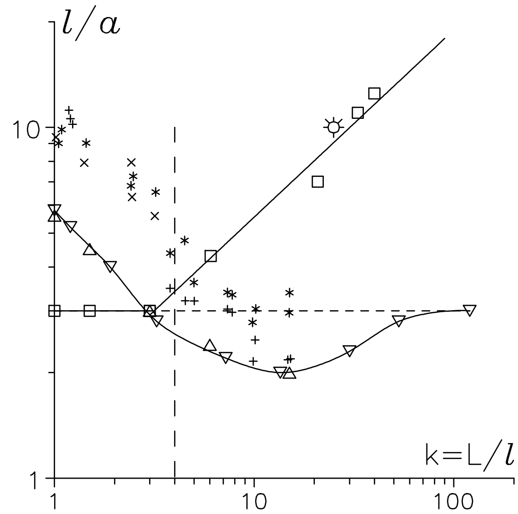


Fig.5. Experimental profiles of velocity on distance at subcritical and critical initiation.

Fig.6. Classical parameter of cylindrical DW diffraction *l*/*a* as function of ratio L/*l* of geometrical sizes of charge with intermediate symmetry.

Some results of DW initiation by charges of rectangular form with different ratio *k=L/l* is illustrated on Fig.6 from point of view of cylindrical symmetry, when at ideal case only single parameter – ratio of charge size *l* to cell size *a* – is important. Symbols +, ×, * correspond to diffractional DW reinitiation in half-space (data of [1,2]) for mixtures 2H2+O2+zN2, C2H2+2.5(O2+zN2) and C2H4+3(O2+zN2) respectively (P_0=0.1 MPa). The remaining symbols correspond to mixture C2H2+2.5O2: reinitiation in half-space – 1) Δ - for L=const and variable *l*; – 2) ∇ - for S=L×*l* =const and variable L and *l*; reinitiation in the gap – 1) □ - for *l*=const and variable δ (δ is distance among parallel walls of gap, similar to depth of flat channel, *l* is similar to channel width); – 2) point "sun" refer to reinitiation at DW diffraction in plane channel *l*×δ=25×1 mm from [3]. Horizontal dotted line corresponds to asymptotic value l_{**}/a=3 for cylindrical initiation; vertical dotte line correspond to k=4, when the rectangular form of initiator develops the cylindrical symmetry in accordance with [4].

4 Estimations

In accordance with experimental results for many mixtures (for example, -fig.5) devoted to spherical, cylindrical and plane initiation the next formulas can be proposed for r_{min} and r_{form} at critical initiation regimes:

$$r_{min} \approx 2b\,\nu, \quad r_{form} \approx 2\, r_{min},$$

here b is longitudinal size of detonation cell. These formulas can be used for classification of charge symmetry, based on correlation of geometrical sizes of initiator with the characteristic size of DW formation in gaseous mixture. A quantitative relation between the characteristic scales determining the excitation and propagation of cylindrical and spherical detonation waves can be proposed taking into account the method for diffraction reinitiation of multifront detonation, where the point of collision of rarefaction waves on channel axis corresponds to r_{min}. At this moment the diffracting wave has the symmetry, closed to quasi-ideal: spherical at DW transition from tube to half-space, cylindrical at DW transition from narrow channel to wider. So, the additional formula can be written for spherical (ν=3) and cylindrical (ν=2) cases:

$$6b \approx 0.9d_{**}, \qquad 4b \approx 0.9l_{**}.$$

Latest formulas can be rewrited:

$$d_{**}/a \approx 11, \quad l_{**}/a \approx 7.4, \quad d_{**}/l_{**} \approx 1.5.$$

Using there formulas and schema on fig.1 the next criteria can be proposed for classification of charge symmetry:

$$k \le 2 \text{ – spherical; } k > 3 \text{ – cylindrical.}$$

With the help of above formulas the relation about critical initiation energy can be written as

$$E_{3*}/E_{2*}=18b, \qquad E_{2*}/E_{1*}=25b.$$

Proposed relations found to be in agreement with experimental data.

5 Conclusions

The criteria for classification of charge symmetry is proposed, based on correlation of geometrical sizes of initiator with the characteristic size of DW formation in gaseous mixture.

6 Acknowledges

This investigation was sponsored by Russian Foundation of Basic Researches – grant 08-01-00347.

References

[1] Benedick W. B., Knystautas R., Lee J. H. (1984). Large-scale experiments on the transmission of fuel–air detonations from two–dimensional channels. In: Progress in Astronautics and Aeronautics (Dynamics of Shock Waves, Explosions and Detonations) 94: 546.

[2] Lui Y. K., Lee J. H., Knystautas R. (1984). Effect of geometry on the transmission of detonation through an orifice. Combust. Flame 56: 215.

[3] Mitrofanov V. V., Soloukhin R. I. (1964). On the diffraction of a mulifront detonation wave. Dokl. Akad. Nauk SSSR 159: 5, 1003.

[4] Vasil'ev A.A. (1998). Critical conditions of initiation of cylindrical multifront detonation. Comb. Explosions$Shock Waves 34: 2, 114.

[5] Vasil'ev A.A., Mitrofanov V.V., Topchian M.E. (1987). Detonation waves in gases. Comb. Explosions$Shock Waves 23: 5, 109.