Time–dependent dynamics of the reaction front propagation in detonation structure

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Introduction

The fundamental feature of the propagation of a detonation wave is cell generation. The size of the detonation cell defines the characteristic length scale at which the detonation front recovers peak flow parameters, i.e., pressure, temperature, and energy release, and in this way self-sustains the non-decaying propagation. Because of this process, the cell size is an important scale factor characterizing the structure and macroscopic behavior of detonation wave under stable and transient conditions [1-3].

It was shown that often the evolution of detonation structure along the tube could be considered as a sequence of quasi-stationary states, which have the cell size and the cell symmetry of the single detonation modes of different orders [4]. When the state of single mode has become fully established the structure of flow and energy release inside the detonation front develop strictly periodically along the tube at one mode frequency inversely proportional to the cell length of the mixture. At these conditions the propagation of detonation could be considered as a movement of giant macroscopic oscillator propagating by a regular manner. From experimental and theoretical points of view it is interesting to establish critical flow parameters released in this structure before and after termination of the cell cycle. This work addresses to systematic study of time–dependent dynamics of reaction front propagation along marginal and normal detonation structure in round tubes.

Experimental Setup

The propagation of a detonation wave was investigated in round steel detonation tubes with inner diameters of *25.3* and *50 mm* (Fig.1). Aspect ratios of the tubes *L/d* (length over diameter) were more than *200* to ensure an adequate travel for the observation of stable detonations. The *60* and *100 mm* sections containing a driver gas, usually a stoichiometric $C_2H_2+2.5O_2$ mixture, were used to provide the initiation. The pressure of a driver gas was usually made higher than that of the experimental mixture in order to initially overdrive the detonation. In order to secure the stable velocity regime in the measuring parts of the detonation tubes a minimum pressure ratio between the driver gas and working mixture was maintained prior to initiation. For all experiments, stoichiometric $C_2H_2 – Air$ and $3.5\%\ C_2H_2+26.5\%\ O_2+70\%\ Ar$ gas compositions at different initial pressures and ambient initial temperature were used..

Ion gauges and pressure transducers measured detonation velocity and pressure, and smoked foils recorded the detonation structure. The measuring sections of *25.3* and *50-mm* tubes were equipped with nine and twenty-eight ports placed at equi-spaced intervals, respectively. The step between ports was equal to a half- and a quarter-length of the spin pitch πd of spinning detonation, where d is the diameter of the tube. Each port consisted of four ion gauges. Thus, the velocity evolution of reaction zones and shock fronts has been carefully studied over the lengths of *31.6* and *105 cm*. The *29-cm*-and *24-cm* end parts of the tubes

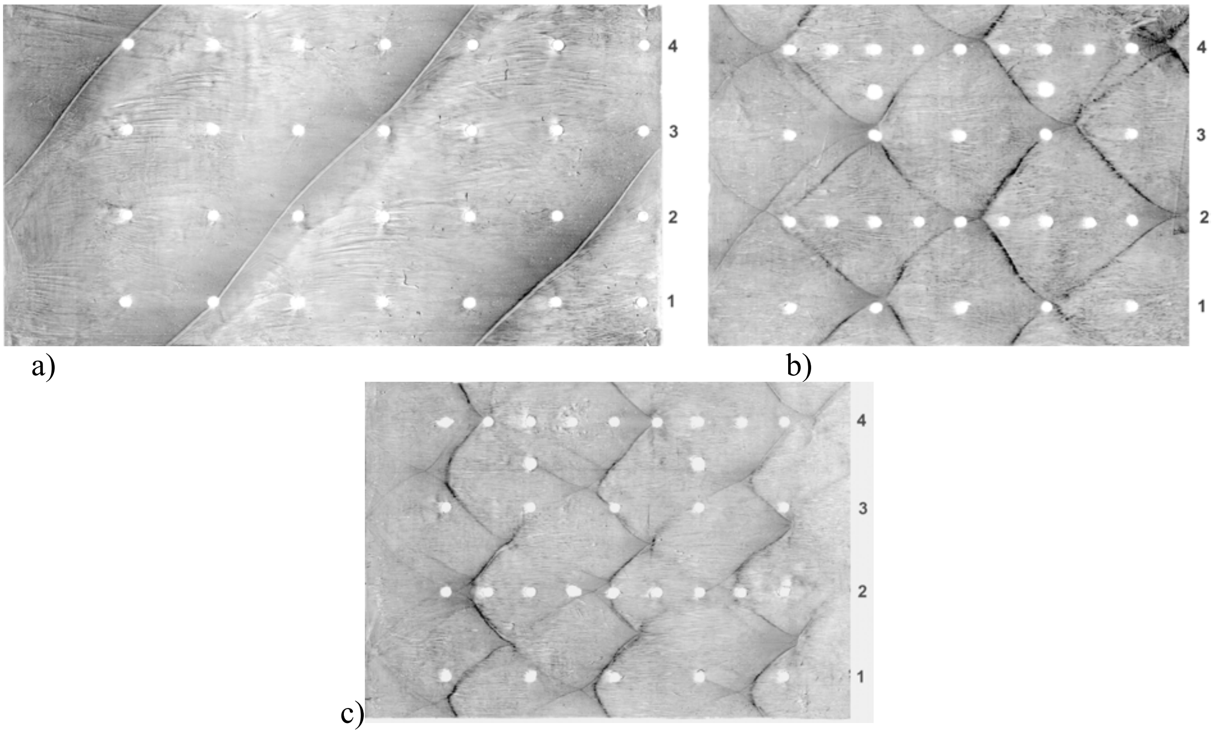


Fig. 1. Soot imprints of detonation propagating along the tube of *50 mm* in diameter and positions of ion and pressure gauges with respect to the smoked foil: A- spinning detonation; b – two-cell detonation; c – three-cell detonation. Mixture $3.5\%\ C_2H_2 + 26.5\%\ O_2 + 70\%\ Ar$.

were used in order to obtain soot imprints of the detonation travel. These parts were connected to the main channel without changing an open flow area and equipped with a mechanical system to fix smoked films. Figure 1 illustrates the typical arrangement of ion and pressure gauges with respect to smoked foils for spin, two-cell and three cellular detonation structure. As is seen in the figure 1 this technique allows measuring longitudinal velocity evolution of reaction front along the detonation structure with an acceptable spatial resolution.

Results

As the critical value of the initial pressure in both tubes is approached the detonation velocity decreases rapidly. As is seen on the Fig. 2, the deficit with the CJ detonation velocity reaches a maximum at the pressure range *I* (spinning detonation) in both tubes and decreases slowly as the initial pressure grows. The deficit in the CJ detonation velocity is larger in a smaller tube. The level of critical pressure in *50-mm* tube is three times less than the corresponding one in the smaller tube, even though the values of critical velocities are very close to each other. The difference between velocity curves reaches a maximum at the pressure range *I* (spinning detonation), and decreases slowly as the sensitivity of the mixture and initial pressure increase. This effect is substantial for marginal spin, one-cell and two-cell detonations (pressure ranges *I*, *II*, in Fig. 2) in circular tube when the cell size of the mixture is more than one tube diameter. In these cases, the intensification of energy release due to interactions of transverse detonations with the tube wall is the main mechanism for maintaining the wave propagation at a higher velocity. Under these conditions, the influence viscous effects at the walls on the detonation velocity and cell length are the largest. As the initial pressure or tube cross section grow, the new zones of high energy release formed by collisions of transverse waves in the inner tube volume gradually start to dominate the detonation propagation (pressure range *III* for three-cell normal detonation in Fig.2). In a high-pressure region, the energy release outside the walls determines the structure and velocity of detonation. Consequently, the velocity deficit of D_{CJ} (Fig.2) in both tubes decreases slowly and tends towards to the natural limit, which is defined by boundary-layer effects and heat losses to the wall.

Ion gages measurements also provided a tool for monitoring the reaction zone shape during detonation travel. The dependence of the curvature of the detonation front on the initial pressure of the mixture is presented in Figure 3. The curvature S_{flame} was defined as the distance between near and far edges of reaction front along the tube. For normal detonations at high pressures, the detonation front approximately could be considered as a plane. The front curvature is negligible in comparison with the diameter of the tube. For two- and one-cell marginal detonations, the curvature of the reaction front increases rapidly and reaches a peak value $S_{flame} \cong 1.1R$ in both tubes for spinning detonations, where, R is the radius of the tube. This result is consistent with earlier observations of Ul'yanitsky [5], who studied the bulk structure of single-head spin detonations by means of pressure transducers. For maximum curvature of the leading shock front of the spinning wave, his measurements give the same value $S_{shock} \cong 1.1R$. Thus, on the basis of these observations one can conclude that the radius of the tube can play a role of a dimensional parameter describing the bulk structure of marginal detonations.

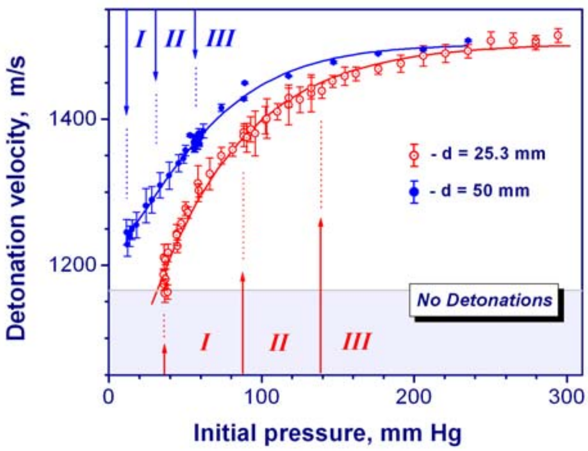


Fig. 2. Detonation velocity vs. initial pressure in round tubes. in tubes of 25 and 50 mm in diameter. Mixture $3.5\%\ C_2H_2+26.5\%\ O_2+70\%\ Ar$.

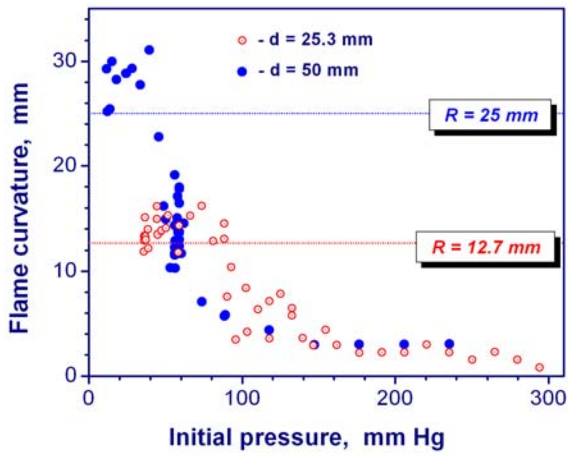
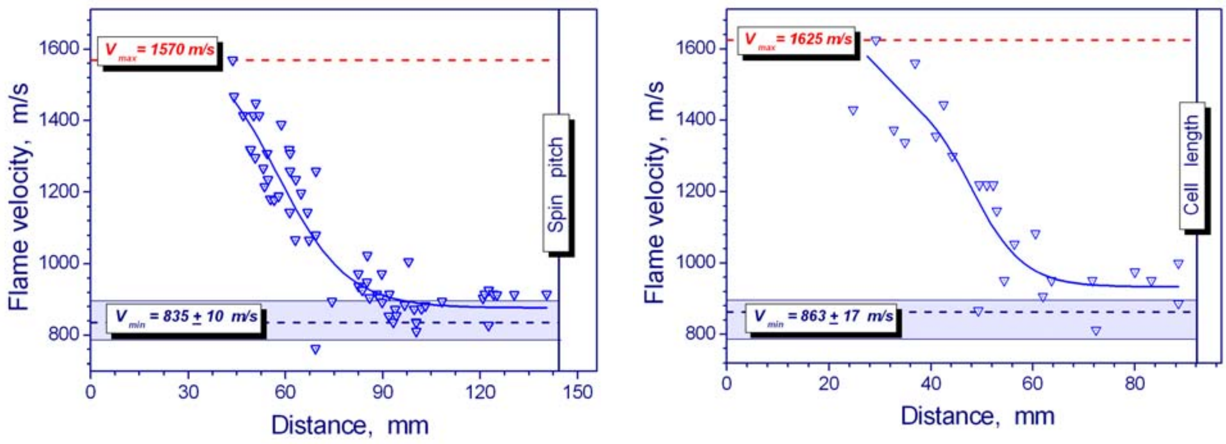


Fig. 3. The reaction front curvature of detonations vs. initial pressure of the mixture in tubes of 25 and 50 mm in diameter. Mixture $3.5\%\ C_2H_2+26.5\%\ O_2+70\%\ Ar$.

Significant velocity fluctuations of the reaction front were recorded over test sections for marginal and normal detonations. The detonation velocity has a tendency to oscillate: a property that becomes very pronounced especially for single-head spinning detonations. Towards the completion of cell cycle, in all studied cases a detonation recovered the velocity peak with a following decay of flame velocity to the some critical value, which was very close to the sound speed of the burnt products (Fig .4). Blue strip lines in the fig. 4 correspond to the range of flame velocities, which are between isobaric and isochoric sound speed of combustion products obtained from thermochemical equilibrium simulations. Because of the scatter of velocity data caused by an arbitrary dispositions of measurement intervals with respect to the detonation structure the lowest velocity values in the graphs (fig.4) should be considered as a closer to limiting one. The upper velocity level for both marginal and normal detonations is almost two times more the value of an isobaric sound speed of combustion products.



a) b)

Fig. 4. Velocity of reaction front along the marginal detonation structures in round tube of 50 mm in diameter: a –single-head spinning detonation; b –two-cell marginal detonations. Mixture *3.5% C_2H_2+26.5% O_2+70% Ar*.

Conclusions

Time–dependent dynamics of the reaction front propagation along marginal and normal detonation structure in a round tubes were investigated. It was shown that before completion of the cell cycle in all studied cases a flame velocity decays to the some critical value, which are very close to the isobaric sound speed of burnt products. The upper velocity level for both marginal and normal detonations at the beginning of the cell cycle is almost two times more the value of an isobaric sound speed of the mixture.

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