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EMISSION METHOD OF INVESTIGATION OF THE CELL STRUCTURE OF MULTIFRONT GAS DETONATION

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An emission method for measuring instantaneous and averaged parameters of the cell structure of multifront gas detonation is developed. The method is based on photoelectric detection of the dynamics of changes in the inherent emission due to combustion of the combustible mixture in the detonation wave.

Introduction. Recent decades are characterized by increased interest in the gas detonation phenomenon that is related to technological and power-engineering problems and to the problem of explosion safety in the mining industry, technology, and power engineering. Although on the whole the behavior of detonation waves is satisfactorily described by a one-dimensional theory, detailed investigations reveal a complex cell structure of the detonation wave front in all gas mixtures without exception [1-3].

The overwhelming majority of modern investigations are based in one way or another on the concept of the cell structure of the detonation wave. The cell size has become the main characteristic dimension used as a yardstick to which scales of the phenomena observed are compared, including sizes of chemical-reaction zones, diameters of detonation pipes and loads, geometrical sizes of channels, zones of the energy distribution upon initiation, etc. The mean cell size retains its role of the basic linear scale also in the case of nonstationary motion of the detonation wave as a whole, e.g., in critical phenomena of propagation from a narrow channel to a wide one and initiation of gas detonation [4, 5].

As a rule, measurements of the size of a detonation cell are based on processing trace impressions left by a detonation wave on a detonation pipe wall covered with a sensitive film. Cell structures left on trace impressions have different degrees of regularity and can be divided in this respect into three classes: regular, irregular, and intermediate (quasiregular) [6]. The first type of structure is observed in mixtures with substantial additions of a chemically inert diluent. Irregular structures are typical of fuel–air mixtures, and intermediate ones are typical of most fuel–oxygen mixtures. We note that even in the case of the fuel–oxygen mixtures most frequently used in laboratory experiments, various approaches to evaluation of the detonation-cell size by the trace method yield values differing by a factor of 1.5–2. All the more, this takes place for mixtures with irregular cells. Thus, because of the basic importance of the concept of cell size in detonation physics, development of new experimental methods for its evaluation is one of the central problems important in practice.

In the present work, an experimental method for measurement of the detonation-cell size is implemented that is based on photoelectric detection of the dynamics of the inherent emission due to combustion of a combustible mixture in a detonation wave. Modulation of the emission along the detection direction is provided by the pulsating character of the propagation of the multifront detonation that occurs as a result of periodic collisions of transverse detonation waves and combustion of the investigated mixture behind them with the corresponding induction period.

Experimental. The investigation was carried out on the experimental facility whose schematic diagram is presented in Fig. 1. The setup is based on a detonation pipe made of stainless steel with a length of 3.84 m and an internal diameter of 25.5 mm. A unit for premix-chamber ignition with a length of 100 mm installed at the end of the detonation pipe and separated from the main channel by a brass diaphragm was used for initiation of detonation. Initiation was effected upon outflow of combustion products formed in the detonative combustion of a $C_2H_2 + 2.5O_2$ mixture from the unit for premix-chamber combustion into the region of the main channel. This

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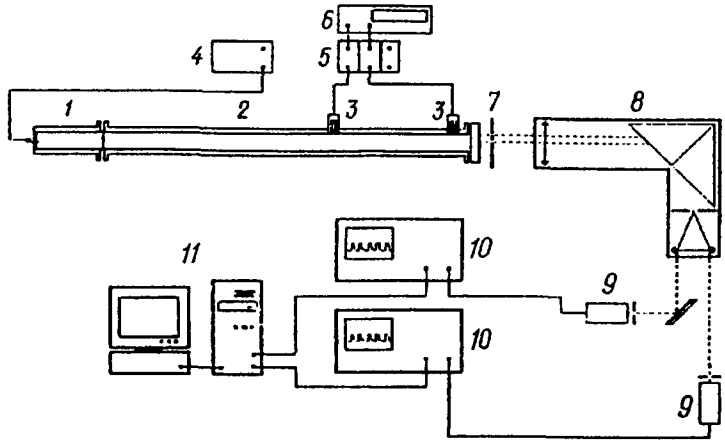

Fig. 1. Schematic diagram of the experimental setup: 1) unit for premix-chamber ignition, 2) detonation pipe, 3) photodetectors, 4) ignition unit, 5) two-channel rectangular-pulse generator, 6) time-interval meter, 7) field aperture, 8) monochromator, 9) photomultipliers, 10) digital oscilloscopes, 11) computer.

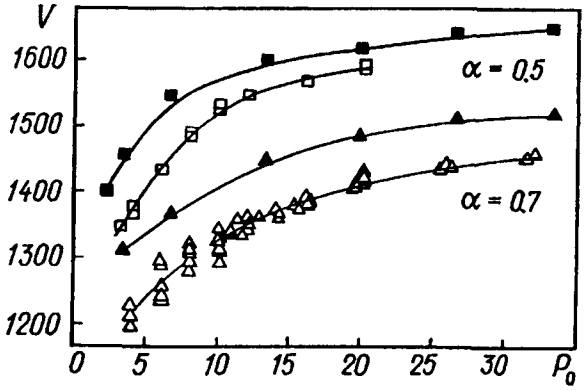

Fig. 2. Dependence of the detonation-wave velocity (V, m/sec) on the initial pressure (P_0, kPa) in a $0.117C_2H_2 + 0.883O_2$ mixture ($\varphi = 0.33$) with different degrees of dilution with argon ($\alpha = 0.5$ and $\alpha = 0.7$) (open symbols) and results from [7] (solid symbols).

ignition scheme made it possible to reduce substantially the time and length of the combustion-to-detonation transition. The measurement zone was situated near the end of the detonation pipe and had a length of 805 mm.

A 3.5% C_2H_2 + 26.5% O_2 + 70% Ar combustible mixture with an increased adiabatic exponent γ and a lowered activation energy, whose detonation front is characterized, according to [7], by a regular cell structure, was used as the working mixture. The mixture was prepared by a manometric method and was stored for two days before use. The channel of the detonation pipe was evacuated twice to a pressure of ~0.13 Pa prior to each measurement. To exclude possible effects of spurious admixtures, the pipe was filled with the working mixture to a pressure of ~6 kPa prior to the repeated evacuation.

The detonation-wave velocity was measured by two photodetectors installed a distance of 805 mm from each other at the beginning and at the end of the measurement zone. The photodetectors were based on FD-256 fast photodiodes and provided a time resolution not worse than $\sim 10^{-9}$ sec. In order to reduce the uncertainty in the arrival time of the detonation wave at the detection cross sections, especially in detonation propagation modes close to spin detonation, the signals from the photodetectors were fed into a two-channel generator of rectangular electric pulses. Its triggering threshold for each of the channels was chosen based on the sensitivity of the diodes. Thus, the circuit for measuring the velocity generated rectangular electric pulses from each of the photodetectors at the instant when the emission intensity behind the front of the detonation wave reached a certain threshold

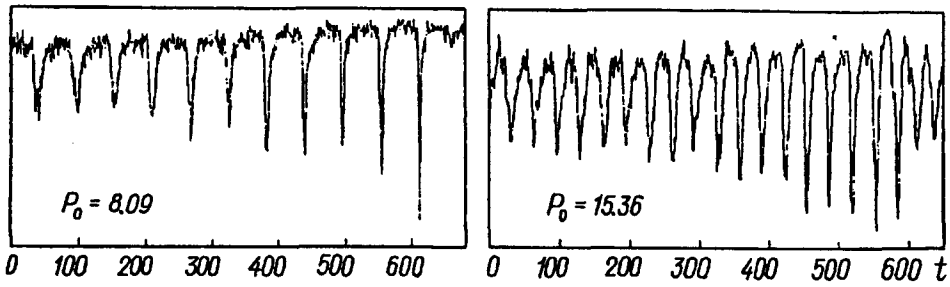

Fig. 3. Typical time-resolved emission traces near the channel wall of a detonation pipe for detonation propagation regimes with one and two cells in a 3.5% C_2H_2 + 26.5% O_2 + 70% Ar mixture (φ = 0.33) with a degree of dilution with argon α = 0.7. t, μsec; P_0, kPa.

value. The electric pulses obtained were used as start and stop pulses for a time-interval meter. Figure 2 presents dependences of the detonation velocity on the initial pressure for a $0.117C_2H_2 + 0.883O_2$ combustible mixture (the fuel excess coefficient φ = 0.33) with different degrees of dilution with argon (α = 0.5 and α = 0.7), which are compared with results from [7]. As is evident from the figure, the detonation-wave velocity measured in our work turned out to be somewhat smaller. This is connected with high thermal losses due to heat transfer to the detonation-pipe walls compared to [7], in which experiments were carried out in a channel with a 32 × 92 mm rectangular cross section. It should be noted that the effect of thermal losses is especially pronounced for the less sensitive mixture (α = 0.7), and the deficit in the velocity detected in the present work starts to decrease with increase in the mixture sensitivity (α = 0.5).

For adjustment of the optical system, the detonation pipe was placed in the field of view of the illuminator of an IAB-451 shadow device. The end of the pipe was equipped with a flange with a built-in plane-parallel quartz window with a thickness of 25 mm. Measurements of cell dimensions in propagation of a detonation along the detonation-pipe channel were carried out by detecting the change in the inherent emission from the region behind the wave front along the direction parallel to the detonation-pipe axis within the spectral range of 400–470 nm. The detection direction and its orientation with respect to the axis were selected using a field aperture mounted immediately behind the exit optical window. To provide a comparison with results of the trace method, one of the directions was chosen close to the wall of the detonation-pipe channel and another coincided with its center. The spectral range of measurements was selected by a slit aperture mounted in the focal plane of the entrance objective of the monochromator. Its dimensions also determined the spatial resolution of the optical system in the measurement zone. Emission signals were detected by photomultipliers with a time resolution of 0.5 μsec and were recorded using S9-8 digital oscilloscopes controlled by a personal computer. To provide additional angular and spatial selection of the transmission of the optical system along the observation direction and to exclude stray light, apertures were mounted in front of each of the photomultipliers.

Results and Discussion. Figure 3 presents typical traces of the inherent-emission dynamics for a detonation propagation regime with one (spin detonation) and two cells in a 3.5% C_2H_2 + 26.5% O_2 + 70% Ar mixture (φ = 0.33, α = 0.7) obtained by the method proposed for different initial pressures of the working mixture. As is evident from the figure, the pulsating character of the multifront-detonation propagation induced by periodic collisions of transverse detonation waves and combustion of the working mixture behind them with the corresponding induction period provides pronounced modulation of the inherent emission along the direction of detection. The character of the signals detected makes it possible to detect reliably the combustion dynamics behind the detonation-wave front in real time. The detonation-cell length was calculated by multiplying the averaged time interval τ between successive maxima (minima) of the emission intensity by the measured detonation-wave velocity: $L = \tau V$.

Figure 4 presents the experimental dependence of the detonation-cell length on the initial pressure for a 3.5% C_2H_2 + 26.5% O_2 + 70% Ar mixture (φ = 0.33, α = 0.7); for comparison, results of the trace method from [7] are presented. It is evident that even with consideration of the above-discussed slight inconsistency in the detonation velocity and the geometry of the channels used, quite good coincidence of the results obtained is observed within the range of initial pressures investigated.

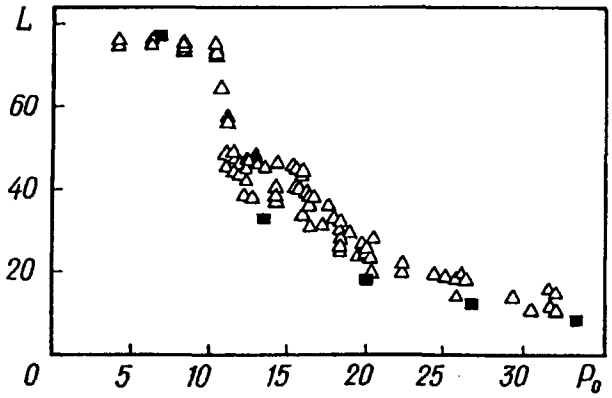

Fig. 4. Denotation-cell length (L, mm) as a function of the initial pressure. Measurements were carried out near the channel wall of a detonation pipe for a 3.5% C_2H_2 + 26.5% O_2 + 70% Ar mixture. Results obtained by the method of photoelectric detection of the inherent emission (open symbols) and results from [7] obtained by the trace method (solid symbols). $\alpha = 0.7$, $\varphi = 0.33$.

Thus, the emission method based on detection of the dynamics of the inherent emission due to combustion of a combustible mixture behind a detonation-wave front makes it possible to carry out measurements of both the temporal and spatial variations in the cell structure of a detonation wave in its propagation. One of the main advantages of the method proposed compared to the trace method consists in the possibility of simultaneous measurements not only on the wall but also within the channel of the detonation pipe. In addition, photoelectric detection of the inherent emission in real time yields information on the dynamics of the three-dimensional gas-dynamic processes and chemical reactions taking place behind the detonation-wave front. Processing of the signals detected makes it possible to monitor both averaged and instantaneous parameters of the cell structure of the multifront detonation and their relationships with particular physicochemical properties of the gas mixture. At the same time, the emission method of measurements can easily be used in combination with the conventional trace method.

Conclusion. The contactless emission method was applied in the present work to measurements of instantaneous and averaged parameters of the structure of a gas-detonation front. The method is based on photoelectric detection of the inherent emission along the direction normal to the wave front. In this method, the amplitude and frequency modulations of the inherent-emission signals are due to the characteristics of the combustion of the combustible mixture resulting from the periodic motion and interaction of transverse detonation waves. We have carried out measurements of the dependence of the detonation-cell length on the initial pressure in a pipe of circular cross section with an internal diameter of 25.5 mm for a 3.5% C_2H_2 + 26.5% O_2 + 70% Ar mixture with a regular cell structure. The values of the detonation-cell length measured within the range of initial pressures of 3.3–33.3 kPa agree well with data obtained by the trace method.

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