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FLUID AND GAS DYNAMICS IN TECHNOLOGICAL PROCESSES

INVESTIGATION OF THE PRESSURE PULSATIONS DOWNSTREAM OF THE FRONT OF A GAS DETONATION WAVE

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A new method is proposed for diagnostics of the cellular structure of a detonation wave on the basis of recording of the gas-pressure pulsations in the shock-wave stub downstream of the front of this wave with the use of piezoelectric transducers. Spectral analysis of the signals recorded allows one to exactly determine the range of possible sizes of a detonation cell and the probability-distribution function of the cellular-structure states.

The interest shown in detonation combustion in the last decade is explained by the fact that this effect can be used in rocket and aircraft engines of the new generation as well as by the need for solving problems on explosion safety in mining, production processes, and power engineering. The main feature of a detonation wave propagating in any fuel mixture is that it has a front with a complex cellular structure. The length scale determining the periodicity of the elements of the spatial cellular structure of a gas detonation wave (size of a detonation cell) represents the main characteristic distance, within which the local values of the maximum energy release are restored due to the self-organization of the gas flow in the detonation wave front, with the result that the wave continues to propagate with a maximum velocity. Because of this, the size of a detonation cell is considered as one of the universal dimensional parameters used for determining the linear scales of the detonation effect: the sizes of the zones of a chemical reaction, the diameter of detonation tubes and charges, the geometric sizes of channels, and the energy-distribution zones formed in the process of initiation of a wave [1–4].

Among the few diagnostic methods of investigating the structure of a detonation wave, the track method has gained the widest acceptance. This method is based on measurement of the average longitudinal or transverse size of the cellular structure of the track impressions left by a detonation wave on a sensitive soot layer deposited on the wall of a detonation tube (Fig. 1). Along with the obviousness and simplicity, this method has a significant limitation — it does not provide a high accuracy of measurements in gas mixtures having an irregular cellular structure [5], to which the majority of the most widely used fuel–air and fuel–oxygen compounds belong. Different approaches to determination of the dominating size of a detonation cell in such mixtures with the use of the track method give values differing from one another by 1.5–2 times. Moreover, track impressions can be recorded only once; to repeat measurements, it is necessary to deposit a new soot layer. At the same time, to investigate the regularities of the evolution of a detonation wave in different-geometry channels and pulsed-periodic detonation apparatus, it is frequently necessary to perform quasicontinuous measurements of the current structure of the wave in real time. In [6, 7], a contactless emission method has been developed for determining the dynamics of the change in the front of a detonation wave. This method is based on photoelectronic recording of the intensity of the proper glow of a gas in several directions perpendicular to the front of a wave. However, the existing technological equipment makes the use of this technique difficult because, in this case, the serving personnel should be highly qualified to control the complex optical image systems sensitive to vibrations. The aim of the present work was to develop new methods

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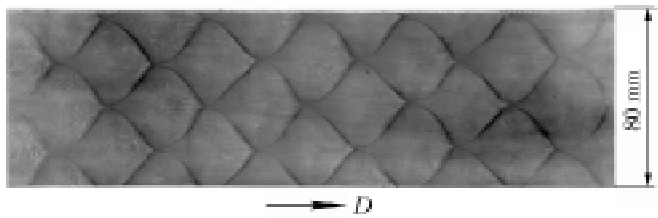

Fig. 1. Track impression of a detonation front on the walls of the channel of a tube.

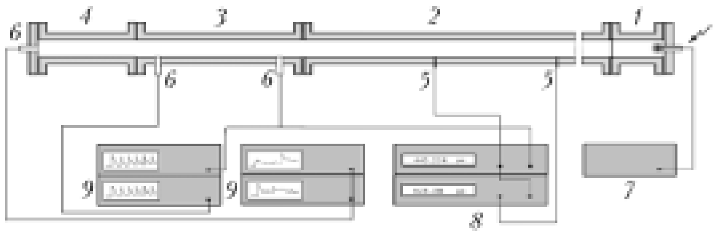

Fig. 2. Setup for measuring the pressure pulsations downstream of the front of a detonation wave: 1) ignition chamber; 2) detonation tube; 3) measuring unit; 4) unit for obtaining track impressions; 5) ionization transducers; 6) piezoelectric pressure transducers; 7) ignition unit; 8) time-interval counters; 9) digital oscilloscopes.

of diagnostics of the structure of a detonation wave and to adapt these methods to the conditions realized in continuous and pulsed-periodic detonation apparatus.

We have developed a new method for measuring the cellular structure of the front of a detonation wave, which is based on recording of the gas-pressure pulsations in the shock-wave stub downstream of the wave front with the use of piezoelectric pressure transducers. A detonation is characterized by the fact that it gives rise to transverse shock waves or detonation waves [1, 8–10] that propagate at a practically right angle to the front of the leading compression shock and integrate with it in the form of triple Mach configurations. In the process of propagation of transverse waves, a gas mixture is burnt out in the induction zone between the leading shock wave and the flame front. A high explosion energy released by the gas compressed and heated by the shock wave forms an intense shock-wave stub in the combustion products downstream of the detonation-wave front, which extends to several tens of gauges along the channel of a detonation tube. The interaction of the transverse shock waves, reflecting periodically from the walls of the tube, leads to the appearance of pressure pulsations in the combustion region. The frequency of these pulsations is determined by the number of transverse waves forming a detonation and, consequently, carries current information on the cellular structure of its front.

Figure 2 shows a diagram of an experimental setup. The pressure pulsations and the velocity of a detonation wave were measured by two piezoelectric transducers 6 positioned at a distance of 31.8 cm from each other. For the purpose of comparison, the data obtained were correlated with the results of track measurements. Track impressions were obtained in the section (of length 32 cm) of the channel of a detonation tube downstream of pressure transducers 4. The experiments were carried out with a gas mixture of 3.5% C_2H_2 + 26.5% O_2 + 70% Ar, having a large adiabatic index, a low activation energy, and a fairly regular cellular structure.

The characteristic pulsations of the pressure downstream of the front of a gas detonation wave, obtained at different initial pressures of the working mixture, are presented in Fig. 3a and b. It is seen that, despite the gradual decay of the pulsations downstream of the wave front, their amplitude is sufficiently large to be recorded by pressure transducers within several hundred microseconds. Using the Fourier transform, we performed spectral analysis of pressure signals, which allowed us to separate the dominating frequencies from the total spectrum of the recorded pulsations. Figure 3c and d shows the characteristic power spectra of the pressure pulsations downstream of the front of the detonation wave at the pressures indicated in Fig. 3a and b. The periods of pulsations $T_i = 1/\nu_i$ corresponding to the frequency components with a maximum square of the normalized amplitude $C(\nu)^2$ determined the set of dominating frequencies in the total spectrum of pulsations in the shock-wave stub downstream of the detonation-wave front. The

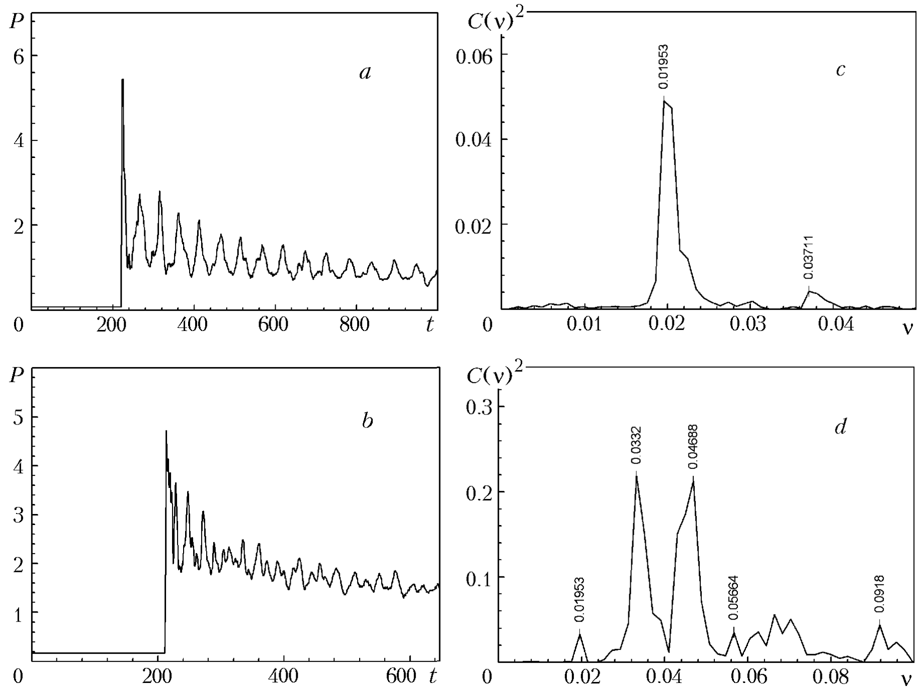

Fig. 3. Characteristic oscillograms of the pressure pulsations downstream of the front of a gas detonation wave (a, b) and their power spectrum (c, d) at different initial pressures of the working mixture: P_0 = 58.8 (a, c) and 125 mmHg (b, d). P, atm; t, μsec.

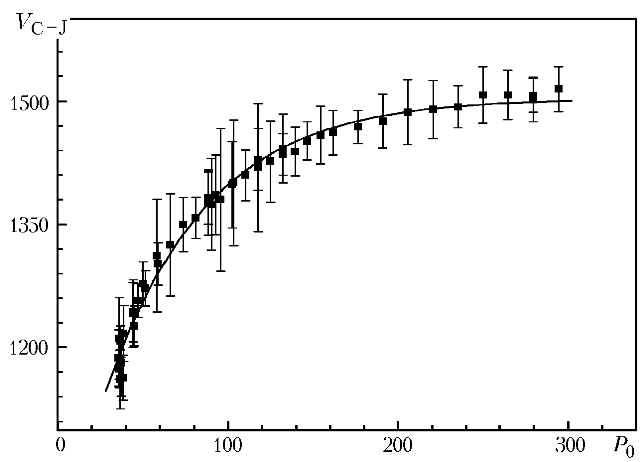

Fig. 4. Dependence of the velocity of a detonation wave on the initial pressure for given experimental conditions. $V_{C\text{–}J}$, m/sec; P_0, mmHg.

velocity of propagation of a detonation wave $V_{C\text{–}J}$ was measured simultaneously (Fig. 4), which allowed us to determine the possible sizes of a detonation cell with the use of the simplest relation $L_i = T_i V_{V\text{–}J}$.

The dependences of the dominating length of a detonation cell on the initial pressure of the mixture, measured with the use of two piezoelectric transducers, and the data obtained by the track method are compared in Fig. 5. It is seen that, practically throughout the range of pressures used, the experimental points coincide within the limits of the quadratic mean error of track measurements.

Thus, the diagnostic method proposed allows one to adequately control the current state of the cellular structure of the front of a detonation wave. Spectral analysis of recorded signals gives exact information on the possible sizes of a detonation cell and the probability distribution function of the cellular-structure states. Moreover, the method

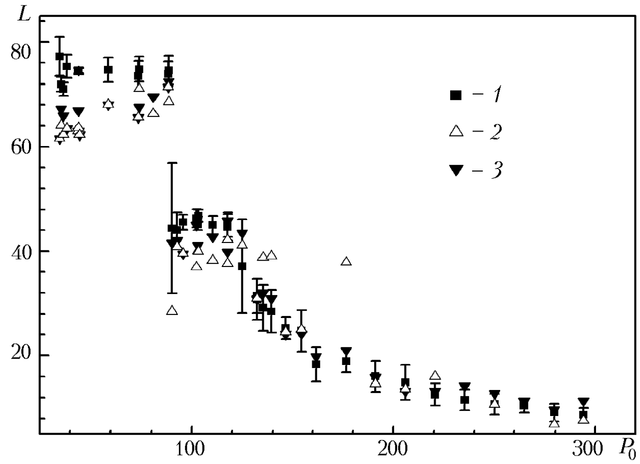

Fig. 5. Dependence of the length of a detonation cell on the initial pressure of the working mixture: 1) measurements of the average length of a detonation cell by the track method; 2, 3) results of measurements of the pressure pulsations downstream of the front of a detonation wave in different sections of the detonation tube. L, mm; P_0, mmHg.

proposed allows one to interpret the most frequently occurring regimes of propagation of detonation waves having an unstable structure with large statistical completeness and value.

NOTATION

$C(\nu)^2$, square of the normalized amplitude; D, velocity of a detonation wave, m/sec; L, length of a detonation cell, mm; P_0, initial pressure of the working mixture, atm; P, pressure downstream of the front of a gas detonation wave, atm; T, period of pressure pulsations, sec^{-1}; $V_{C\text{–}J}$, velocity of a Chapman–Jouguet detonation wave, m/sec; ν, frequency of pressure pulsations, MHz.

REFERENCES

1. R. I. Soloukhin, *Shock Waves and Detonation in Gases* [in Russian], Fizmatgiz, Moscow (1963).
2. A. K. Oppenheim and R. I. Soloukhin, Experiments in gasdynamics of explosions, *Ann. Rev. Fluid Mech.*, **5**, 31–58 (1973).
3. J. H. S. Lee, Dynamic parameters of gaseous detonation, *Ann. Rev. Fluid Mech.*, **16**, 311–336 (1984).
4. A. A. Vasil'ev, V. V. Mitrofanov, and M. E. Topchiyan, Detonation waves in gases, *Fiz. Goreniya Vzryva*, **23**, No. 5, 109 (1987).
5. J. C. Libouton, A. Jacques, and P. J. Van Tiggelen, Cinétique, structure et entretien des ondes de detonation, in: *Actes du Colloque International Berthelot–Vieille–Mallard–LeChatelier*, Vol. 11, Bordeaux, France (1981), pp. 437–444.
6. O. V. Achasov and O. G. Penyaz'kov, Emission method of investigation of the cell structure of a multifront gas detonation, *Inzh.-Fiz. Zh.*, **72**, No. 2, 201–205 (1999).
7. O. V. Achasov and O. G. Penyazkov, Dynamics study of detonation-wave cellular structure: 1. Statistical properties of detonation wave front, *Shock Waves*, **11**, No. 4, 297–308 (2002).
8. B. V. Voitsekhovskii, B. E. Kotov, V. V. Mitrofanov, and M. E. Topchiyan, Optical studies of transverse detonation waves, *Izv. SO AN SSSR*, No. 9, 44, (1958).
9. R. I. Soloukhin and M. E. Topchiyan, Study of the stub of a spin detonation, *Dokl. Akad. Nauk SSSR*, **127**, No. 4, 772–773 (1959).
10. Yu. N. Denisov and Ya. K. Troshin, Structure of a gas detonation in tubes, *Dokl. Akad. Nauk SSSR*, **125**, No. 1, 110–130 (1959).