ГИДРОДИНАМИКА, ТЕПЛО- И МАССООБМЕННЫЕ ПРОЦЕССЫ, ЭНЕРГЕТИКА

УДК 536.46,662.3

V. N. Aleksandrov, B. D. Dinovetsky, A. V. Kostochko

ABOUT THE UNSTEADINESS OF PROPELLANT COMBUSTION AT HIGH-PRESSURE AREA

Keywords: propellant, unsteady combustion, variable pressure.

The results of experimental studies of propellant combustion at alternating pressure, indicating about unsteadiness of propellant combustion in the high pressure area.

Ключевые слова: порох, нестационарное горение, переменное давление.

Приведены результаты экспериментальных исследований горения пороха при переменном давлении, свидетельствующие о нестационарности горения пороха в области высоких давлений.

Due to the fact experimental studies of unsteady propellant combustion have been carried out only at low pressures [1-3] , and the results of theoretical works [4,5] are contradictory , there is currently no common view with regard to the occurrence of unsteady effects at high pressures.

In this report, we present experimental evidence of the occurrence of unsteady effects at high pressures and estimate the limits of their existence.

In the experiments, the variation of propellant sample sizes during combustion with pressure increase or decrease was recorded be means of high-speed filming. The burn rate was determined by the results of streak recording. Simultaneously with the filming , pressure was measured in the combustion chamber.

Three series of experiments with an NDT type ballistite propellant have been carried out: in the first series, the propellant burn rate was determined at increasing pressure; in the second series, the propellant burn rate in going from one pressure level to another higher one was determined; in the third series, the propellant burn rate at increasing pressure was determined by its extinction due to pressure drop [6].

The results of the first series have show that the mean values of burn rates measured at the pressure increase rates 450, 1120 and 1510 MPa/s virtually coincide with the steady burn rates. At the pressure increase rates of 2122 and 9720 MPa/s, the mean values of burning rates agree with the steady values up to pressure ~ 60 MPa and at higher pressures become considerably lower than the steady ones.

At pressure increase rates up to 1510 MPa/s, the propellant combustion proceeded in a steady regime , and at pressure increase rates greater than 2125 MPa/s, unsteady combustion was observed. The rates of pressure increase corresponding to the transition from the steady to unsteady conditions of propellant combustion are within 1510-2125 MPa/s.

In the second series of experiments, after ignition, the propellant combustion proceeded after ignition at increasing pressure and then at almost constant pressure.

In all the experiments(with pressure increase rates ranging from 2400 to 21500 MPa/s), the experimental propellant burn rate at increasing pressure was lower than the steady burn rate , continued to increase at constant pressure and later reached the steady value corresponding to the final pressure level . Experimental significations of the combustion rate at all stages of combustion greatly differ from the fixed rate of combustion, which indicates the non-stationarity of combustion under these conditions. These differences depend on the rate of rising pressure and dimension of the final pressure (Table 1). The higher these dimensions, the longer the delay of the output of the experimental burning speed right to the level of the corresponding final pressure (τ), and the greater the relational excess of the dimension of the experimental combustion rate over the corresponding dimension of the stationary combustion rate (A), the greater the frequency of oscillation of the combustion speed (ν).

It should be noted that the results of the second series of experiments agree with the unsteady combustion theory, the variability of propellant surface temperature [6] and the results of experimental studies at low pressures being taken into account [3].

In the third series of experiments, combustion was interrupted by a sharp pressure drop, and the propellant extinction time was determined, which depended on pressure increase rate at constant parameters of the pressure drop. Moreover it was concluded that, if the extinction time did not vary with the pressure and unsteady otherwise.

The results obtained have shown that the extinction time depends on the pressure increase rate (Table 2), which makes it possible to determine the value of pressure increase rate dividing the steady and unsteady combustion modes. For pressure ~60 MPa, the value of this pressure increase rate is about ~1500 MPa/s, which agrees well with with the results of the two previous series of experiments.

The results of numerous experiments with propellant extinction point to the unsteadiness of propellant combustion at pressure drop, as evidenced by rather high values of pressures at which it is completed (up to 48 MPa),the variable influence of initial temperature, the use of catalysts and combustion

stabilizers for extinction at drops from high to low initial pressures. [7,8]

To estimate the limits of unsteady effects due to the pressure drop in the first approximation, one can assume the value of the critical rate of pressure drop. These values divide not only different combustion modes but also the ranges of propellant burn rates where they are quite different.

A negligible increase in the rate of pressure drop near its critical value leads to extinction and a decrease in the average combustion rate by approximately 2 times, without any variation with a further increase in the rate of pressure drop. The value of critical rate of pressure drop for an NDT type ballistite propellant at pressure ~60 MPa is 2500MPa/s.

In summary, the results of the study point to the occurrence of unsteady effects in propellant combustion at high pressures.

Table 1 - Characteristics of the unsteadiness of propellant combustion in the transition from one pressure level to another

$P_К$, MPa	$P`_П$, MPa/s	A	τ, ms	ν, Hz
19,5	2400	1,08	4,5	28
34	8500	1,2	11,5	30
43,5	18000	2,14	14	38
101	21500	2,86	17,5	102

Table 2 - Time extinction propellant ($\tau_п$) at different rates of pressure rise

$P_Н$, MPa	$P`_{СП}$, MPa/s	$P`_П$, MPa/s	$\tau_п$, ms
70	3244	5868	42
58	3634	5017	35
54	3310	4354	32
63	2968	2337	25
60	2893	2239	26
62	3294	1881	23
57	3081	1556	24

References

1. V.N. Marshakov, O.N. Leipunsky, The physics og combustion and explosion, 3, 2, 231, 1967
2. Yu.S. Ivanshchenko, A.S. Komarov *ibid*, 14, 1, 151, 1978
3. G.I. Zhernosekov,N.A. Karatigin, V.V. Marchenko, O.Ya. Romanov, V.D. Ulitin, P.P. Zheltuhin *Proc.2nd All-Union Symposium on Combustion and Explosion*. Chernogolovka, 1969, 13
4. D.E. Cooker, C.W. Nelson *Trans. ASME: J. Heat Transf., 101, 2, 359, 1979.*
5. Cohen Norman S., Strand Leon D. *AIAA J*, 18, 8, 968, *1979*
6. Novozhilov B.V. *Unsteady Combustion of Solid Propellants.*, Nauka, Moscow, 1973
7. V.N.Aleksandrov, B.D. Dinovetsky, A.V. Kostochko Herald of Kazan Technological University 13, 10, 104-113 (2010)
8. V.N.Aleksandrov, B.D. Dinovetsky, A.V. Kostochko, P.O. Safronov Herald of Kazan Technological University 16, 17, 201-204 (2013)

© V. N. Aleksandrov - Kazan National Research Technological University, labgor@kstu.ru; **B. D. Dinovetsky -** Kazan National Research Technological University, labgor@kstu.ru; **A. V. Kostochko -** Kazan National Research Technological University, labgor@kstu.ru.