PULSE DETONATION ENGINE ON GASOLINE – AIR MIXTURE

Baklanov D.I., Gvozdeva L.G., Scherbak N.B.
IHED IVTAN RAS E-mail: sherbak@hedric.msk.su

INTRODUCTION

The transformation of chemical energy accumulated in fuel into mechanical one is possible by three ways: in customary deflagration burning, in a mode of explosion or in a detonation mode. At detonation burning the combustion products with higher parameters are produced (temperature, pressure, velocity of gases) than in the first two cases. It leads to the higher efficiency at detonation combustion of fuel. The customary deflagration burning is widely applied in internal combustion engines, in air - jet and rocket engines. The efficiency of process in these drives is determined by the process at constant pressure. The detonation combustion is closer to the process at constant volume and consequently is perspective for designing of pulse rocket engines.

Detonation combustion can be carried out with the help of detonation combustion chamber (DCC), furnished by mechanical valves [1, 2] and in valveless systems [3].

The experimental installation created for the study of propagation of detonation waves in channels of variable section [4], contains DCC, which works in a frequency mode both on gaseous, and on liquid fuels in different modes: normal detonation, overdriven detonation and multi-step detonation (MSD) [5-8]. Most perspective for PDE is the usage of liquid fuels, therefore in the present paper we will describe DCC operation on the mixture of gasoline with air.

DETONATION CHAMBER FOR PDE

DCC (with the whole length near 3 m) consists of a forchamber (with the diameter of 22 mm) and a main chamber with the length of 1 m (with the diameter of 83 mm), with the diverging cone with a vertex angle equal 16 degrees between the chambers. At the operation in the mode of overdriven detonation and MSD mode the convergent cone was added at the exit of the main chamber. Diameter of the outlet varied from 10 up to 30 mm depending on a demanded degree of overcompression of detonation. In the forchamber the ignition occurs from the electric spark in the mixing of fuel and oxidizer and the transition to detonation takes place. As a liquid fuel the gasoline was utillized, which was heated before the delivery in DCC. The oxidizer agent was air. The cooling system of DCC walls up to 70°C was applied. The DCC scheme is shown in fig. 1. DCC worked stable on frequencies of 1-20 Hz during several hours. At frequency of 2-3 Hz DCC was successfully applied to covering protective coatings on devices of a utilities equipment.

The DCC was of a valveless type. The main part ensuring a frequency mode were the so-called "gasdynamics valves", the function of which was fulfilled by the mains of fuel and oxidizer agents which are connected with the forchamber straightly, without any mechanical valves [4]. Wave processes inside the mains leads to an overlapping occurred with given frequency of the mains of the fuel and oxidizer agents and to an unchecked ignition being prevented of fresh portions of a combustion-mixture by combustion products of the previous cycle. The latter was reached by the cooling of combustion products in the mains up to the temperature, at which the induction period of the fresh combustible mixture exceeded the time of the contact of fresh mixture with hot combustion products. At non-observance of the requirement the combustion-mixture will be ignited from the combustion products of the previous cycle, instead of from the spark. In this case it was not possible to receive periodic detonation combustion, and DCC worked in a mode of customary deflagration.

CALCULATION OF FREQUENCY CHARACTERISTICS OF DCC

For design of PDE it is desirable to have frequency of detonation waves of 100 Hz and even more. Therefore, the calculation of frequency characteristic for DCC is important for the estimation of possibility of using DCC for PDE. The method of calculation of pulse repetition rate was offered for this type of valveless chamber. The frequency characteristics were calculated for DCC, working on gasoline - air mixture.

DCC operation frequency is a controlled characteristic, depending on the combustion chamber length L_c, its diameter d_c, length l_f of the fuel and oxidizer feeding lines, their diameter d_f, pressure p_1 inside them, the type of the fuel and oxidizer and excess coefficient α. It is possible to estimate the limiting frequency of DDC operation, if we find the time of the cycle.

The time of the whole cycle consists of the following items:

t_1 - period of detonation formation;

t_2 - period of detonation wave propagation inside the DCC;

t_3 - period of adiabatic outflowing of combustion products out of DCC;

t_4 - period of combustion products outflowing out of the fuel and oxidizer feeding lines;

t_5 - period of DCC filling by combustible mixture.

Thus, the frequency of DDC operation was determined by five items.

Calculations were made in gasoline - air mixture of a stoichiometric composition at initial pressure of p_0=100 kPa with three following DCC schemes consisting of a main chamber and a prechamber (fig.2). The volume of the main chamber and the prechamber assumed to be the same for all three schemes. Volume of DCC is equal to 5,41 dm^3, volume of a prechamber is equal to 0,995 dm^3. Volume of the whole DCC is equal to 6,405 dm^3.

The first DCC scheme consists of the main chamber with constant cross – section of 83 mm diameter with the length of L_c=1 m, and the prechamber of 22 mm in diameter with the length of L_p=2 m (fig. 2a). The connection of the prechamber with the main chamber is realized with the help of cone with an expansion angle equal 16°. This angle produced smooth transition of the detonation wave. The filling performs through the headers at the prechamber.

The second DCC scheme (fig. 2b) consists of the main chamber with constant cross – section and the prechamber with the same dimensions as for the first scheme. The only difference is that the prechamber and the main chamber are supplied separately through different feeding lines.

The third DCC scheme (fig. 2c) consists of the main chamber of variable cross – section and the prechamber. Diameter of the prechamber is equal to 22 mm, its length is equal to 2 m, diameter of the middle part of the main chamber is equal to 83 mm, outlet diameter is equal to 40 mm, length of the chamber is equal to 1 m. The prechamber and the main chamber are supplied separately through different feeding lines.

Four variants (1-4) are calculated for the first scheme. Two variants (5-6) are calculated for the second scheme and two (7-8) for the third scheme. Only one parameter was changed in each variant, the others were constant.

Parameters of detonations are the follows: detonation velocity D=1700 m/s, pressure behind detonation wave p_4=2.8 MPa, sonic velocity c=1000 m/s, adiabatic index γ_4=1.2. Parameters of air are: sonic velocity at 100 kPa a=330 m/s, adiabatic index γ=1.4. Initial temperature T_0=290 K (1 variant) or T_0=350 K (2-8 variants). Pressure in feeding lines of air supply p_2=400 kPa (1, 2, 5, 7 variants).or p_2=800 kPa (3, 4, 6, 8 variants). In forth variant diameter of the main chamber is equal to 110 mm, the length was less, the whole volume of DCC is equal to 5,41 dm^3.

The time from the ignition till the moment of formation of the detonation in gasoline is equal to t_1=4.8 ms or 4.1 ms, and the length of predetonation distance is equal to L=1.58 m or 1.5 m [1]. The propagation time of detonation in gasoline-air mixture is equal to $t_2=(L_p+L_c-L)/D$. Times t_3, t_4, t_5 are taken from calculations.

The data of cycle duration t_Σ and possible frequency f are given in the table.

Table

PDE cycle duration (ms) and possible frequencies (Hz) for gasoline – air mixture

Variant	t_1	t_2	t_3	t_4	t_5	t_Σ	f	f_{max}
1	4.8	0.882	1.	1.768	31.19	39.64	25.23	29.45
2	4.1	0.882	1.	1.768	31.19	38.94	25.68	29.45
3	4.1	0.882	1.	0.678	24.35	31.01	32.25	38.42
4	4.1	0.647	0.57	0.438	24.35	30.1	33.22	39.44
5	4.1	0.882	1.	1.768	4.845	12.596	79.39	131.34
6	4.1	0.882	1.	0.678	3.783	10.444	95.75	183.1
7	4.1	0.882	4.307	4.874	7.969	22.13	45.18	58.31
8	4.1	0.882	4.307	1.869	6.222	17.38	57.53	80.65

The maximum possible frequency f_{max} was also given in the table, calculated on the assumption, that detonation is formed instantaneously at the beginning of the prechamber.

The calculation of DCC frequency characteristics has allowed to reveal the factors restricting cut-off frequency of following of impulses.

The longest processes are: the outflowing of detonation products from DCC in ambient space t_3, the outflowing of combustion products from feeding lines t_4 and the filling of the DCC by a new portion of a combustible mixture t_5. Thus, the perspectives of increase of frequency f are connected with the diminution of times t_3, t_4 and t_5.

The increase of frequency of DCC operation, having stationary geometrical sizes, is possible to achieve by magnification of temperature of preheating of gasoline, organization of separate delivery of a combustion-mixture in a forchamber and main chamber, and also by higher compression of air in an air manifold.

For the considered DCC schemes the maximal frequency was equal to 96 Hz.

DISCUSSION

As contrasted to devices of detonation combustion equipped with system of mechanical valves, the valveless DCC used has a series of advantages.

1) There are no mechanical propellented devices, therefore the safe life of operation of the DCC will increase in many times, and the probability of a failure is considerably reduced.

2) The maintenance and periodic revalving is not required, that decreases a cost of operation.

3) The necessity is absent of command system specifying the demanded frequency duty of valves.

In the case of usage of mechanical valves the cycle time will be diminished by the value of t_3, but the time of pressurization $t_6 = t_5$ should be added. Consequently, cycle duration will be equal to

$$t_\Sigma = t_1 + t_2 + t_4 + 2t_5$$

The time t_3 is much less than the time t_5, as it is evident from the table. Therefore, frequency characteristic will be worse and limiting frequency will be diminished too. It should be noted that in this case time t_4 will be also larger, because it should be necessary to consider a time of subsonic outflowing of detonation product from DCC in ambient space.

ACKNOWLEDGEMENTS

The work was partly supported by Grant N68171-00-M-5920 in the frame of ONR propulsion program, headed by G.D. Roy, to whom authors express their gratitude.

REFERENCES

1. N.N. Smirnov, A.P. Boychenko Combustion to Detonation Transition in gasoline - Air mixtures Combustion and Explosion, 1986, No 2
2. Zverev A.N. et al. Detonation coating.- Sudostroenie, 1979
3. Baklanov D. I. et al. About some engineering aspects of detonation combustion regime using.- Combustion and Explosion, 1986. No 2. p.65
4. Baklanov D. I., Gvozdeva L.G., Scherbak N.B. The formation of high pressure gas flow in frequency mode during non-stationary propagation of detonation. AIAA Paper. # 98-2562. 1998
5. Baklanov D.I., Gvozdeva L.G., Davydov A.N., Lagutov Y.P., Sharov Y.L., Scherbak N.B. Anomalous high pressure regions in propagation of detonation waves in a channel with variable cross-section. Intern. Symposium on Hazards, Prevention and Mitigation of Industrial Explosions. Second Intern. Specialist Meeting on Fuel-Air Explosions, Christian Michelsen Research, Fantoft, Norway, 23-28 June 1996
6. Baklanov D. I., Gvozdeva L.G. Non-stationary processes during propagation of detonation waves in channels of variable cross-section.- High temperature. 1995. V. 33. No 6. p. 958-960
7. Baklanov D.I., Gvozdeva L.G., Scherbak N.B. Formation of high-speed gas flow at combustion in the regime of multi-step detonation.- Gaseous and Heterogeneous Detonations: Science to Applications /Edited by G. Roy, S. Frolov, K. Kailasanath, N. Smirnov/ Moscow: ENAS Publishers, 1999, p.141-152
8. Gvozdeva L.G., Baklanov D.I., Scherbak N.B. Multi-Step Detonation Mode and Its Application.- Conference Proceedings 17th ICDERS, University of Heidelberg, Germany, 1999

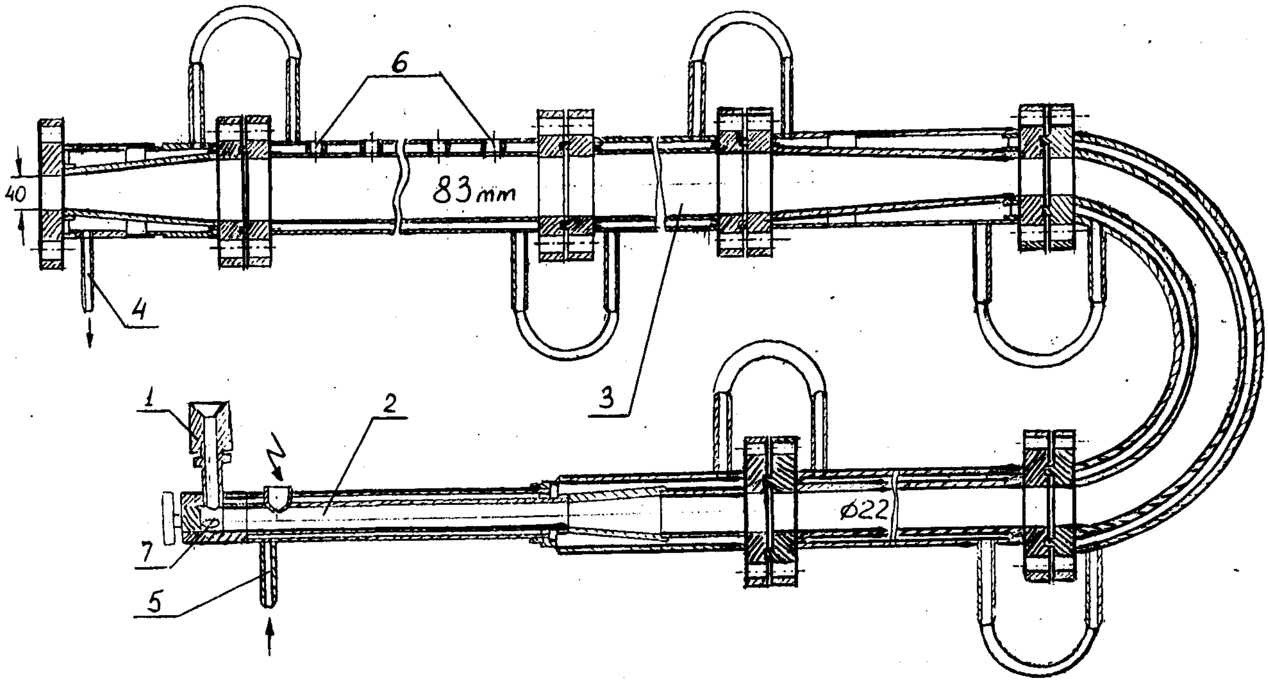

Fig.1 Chamber with variable cross – section with forced cooling
1,7 – inlet holes for fuel and air; 2 – prechamber; 3 – main chamber;
4,5 – outlet and inlet of cooling water; 6 – pressure gauges and photodiodes

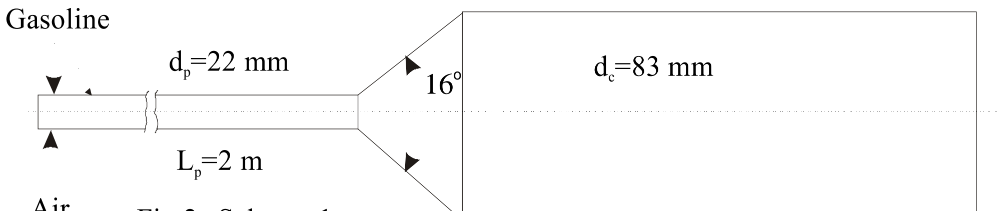

Fig.2a Scheme 1

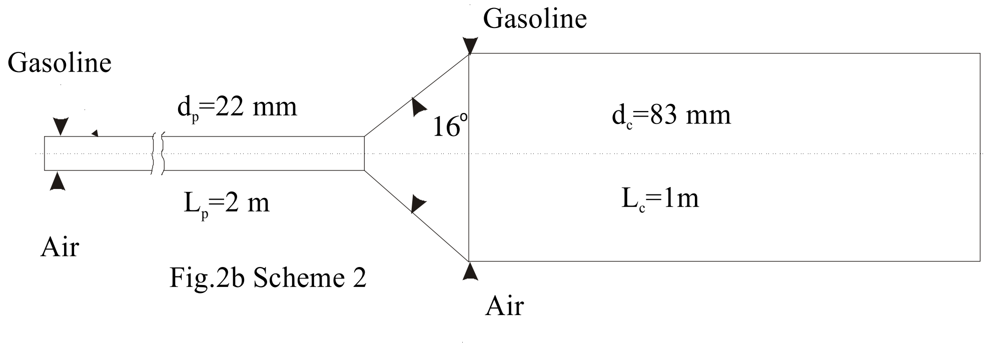

Fig.2b Scheme 2

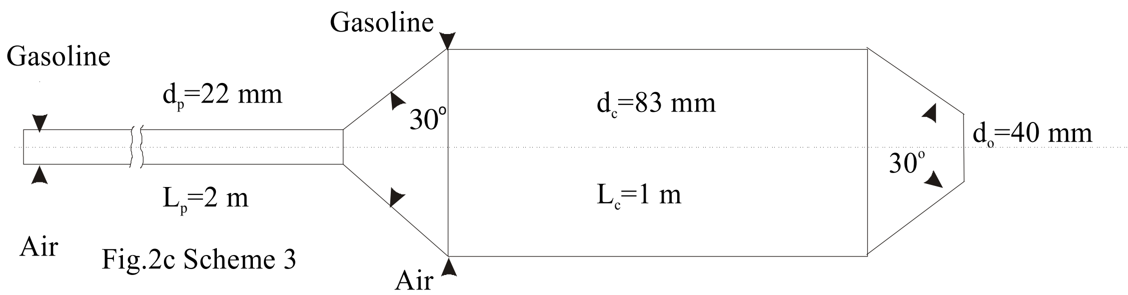

Fig.2c Scheme 3