Detonation Initiation in Moving Non-Premixed Flows

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Introduction

In detonation devices using for practical purposes (evaporation, cleaning of heat-receiving surfaces, crashing of scrap tires, pulse detonation engines) by the reason of safety it is necessary to mix the fuel components directly in detonation combustion chamber (DCC) [1]. Pulsed fuel components supply in DCC provided by fast acting valves or valveless system (so called gasdynamics valves [2,3]). In a comparison with valve systems valveless system have a number of advantages, the main of them are increase of reliability and operation resource of device. Peculiar property of gasdynamics valve operation is unsteady flows in it. This may cause the components mass flow variation with DCC filling. As the result the real detonable mixture composition and flow turbulence in the spark plug location varied. These factors can substantially affect on DDT process. The fuel components mass flow may be varied at the conventional valves using because of the pressure variation in pressure accumulators and DCC. This allows investigating both influence of valveless system operation and real fuel components supply pressure variation on the formation and parameters of detonation.

Fuel components mass flow variation influence on the formation and parameters of detonation in valveless DCC

Investigation of the real composition variation influence on DDT was carried out on the experimental installation presented on fig.1. DCC is tube of 83 mm in diameter and 2500 mm in length. The filling of DCC up with detonable mixture was occurred through the injectors installed in DCC closed end. In the correspondent pressure accumulators of 40 l in volume pressures of oxygen and hydrogen of 6 – 15 atm were installed. After that pneumatic valves were opened and fuel components through the injectors arrived in DCC. Supersonic nozzles and nozzles with resonators [4] were used as injectors. Excessive pressure in DCC of 13.5 l volume was increasing in 1 – 5 atm.

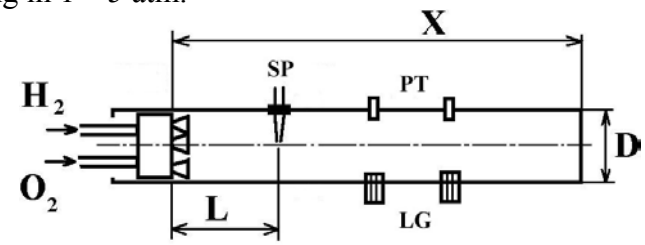

Fig.1. Experimental installation
SP – spark plug, LG – photo gauges, PT –pressure transducers

Pressures in pressure accumulators were decreasing in 0.2 – 0.8 atm. This was lead to the oxygen and hydrogen mass flows were varied with the time of filling (fig.2). The appearance

of resonator on the supersonic nozzle does not affected on the reagents mass flow. In a time after the valves opening the mixture ignition was occurred by the spark plug with energy of 25 J located in the distance of 150 mm from the closed end. After this pneumatic valves were closing. DDT was detected by pressure transducers PCB 113A34 and photo gauges FD 256 readings located in four consequent stations.

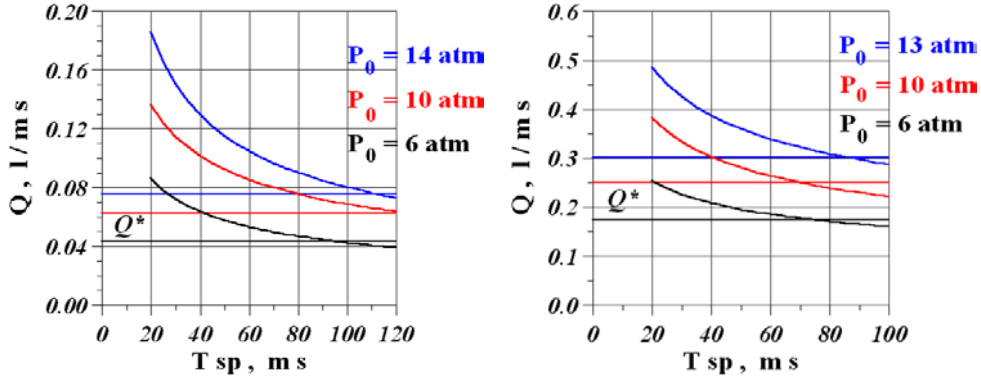

Fig.2. The mass flows of oxygen and hydrogen (liter at normal conditions per millisecond) through the supersonic nozzles at the DCC filling up.

One cycle of valveless PDE operation, which consists of DCC filling up with detonable mixture, detonation ignition, detonation propagation and DCC evacuation, was investigated. Experiments were carried out with hydroxygen mixtures of ER = $(\frac{Q_{H_2}}{2Q_{O_2}})$ equal to 2.3 and 2.6. Delay of mixture ignition after the valves opening was varied that would be corresponded the frequency variation at DDC multi-pulse mode operation.

Dependence of the fuel components mass flow on the time (fig.2) leads to the mixture composition in DCC variation with the time of filling (fig.3). Consequently mixture with higher ER arrives to spark plug location. The ignition energy of this mixture is higher than one of initial mixture. Consequently this will lead to DDT increase. At the same time, detonable mixture initial pressure increase will lead to DDT decrease. Simultaneous action these two opposite directed factors leads to the appearance of the optimal delays region (fig.3).

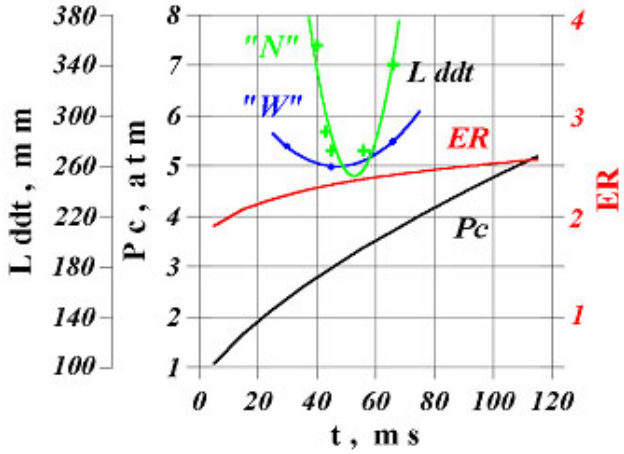

Fig.3. Dependence of DDT length on the time of DCC filling up through the supersonic nozzle “N” and supersonic nozzle with resonator “W”.

It is noted that DDT length is minimal at ignition delays are in the interval of 40-43 ms at the fuel components ignition through the supersonic nozzles. Detonation is forming before second station. In the case of other injectors the optimal delays intervals when the detonation forming on the shorter length at the same initial conditions also were found.
At the nozzles with resonators used as injectors and average mixture ER=2.3 optimal delays interval is 40 to 43 ms, at the average mixture ER increase up to 2.6 the bottom boundary of optimal interval moves up to 65 ms. This result confirms that during DCC filling up with detonable mixture the composition of mixture is varying. At the supersonic nozzles used as injectors and average mixture ER=2.3 optimal delays interval is 45 to 56 мс.

Turbulence influence on detonation formation in flow of nonpremixed fuel components

The influence of detonable mixture turbulence on the DDT was investigated in CH4+O2+N2 mixture. Methane/air mixtures of different degrees of enrichment with oxygen β were used, $\beta = \frac{Q_{O_2}}{Q_{O_2} + Q_{N_2}} \cdot 100\,\%$, where Q_{O_2} - oxygen mass flow, Q_{N_2} - nitrogen mass flow. The velocity of process was determined as average value in a certain base.
The dependence of detonation concentration limits of CH4+O2+N2 mixtures on the flow Reynolds number is obtained. It should be noted that scopes of detonation realization i.e. its concentration limits should be considered conditionally, namely – at more DCC length it may be wider.
The boundary values β restricting the detonation existence region dependence on Reynolds number is presented in fig.4.

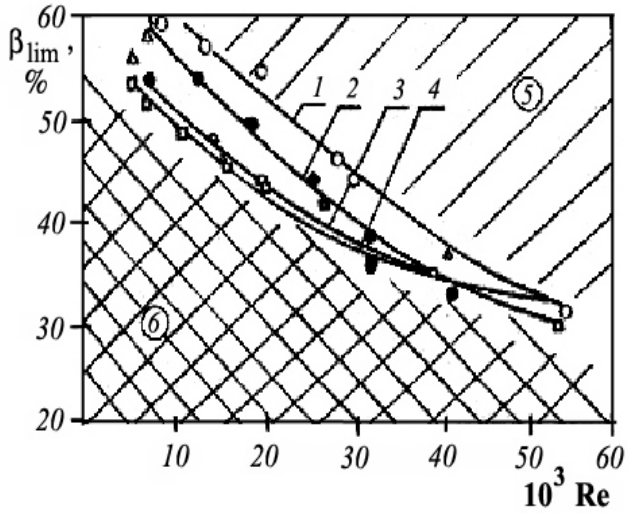

Fig.4. Limitary values of α as function on Re: 1 – ER = 0.625, 2 – ER = 0.71, 3 – ER = 1, 4 – ER = 1.2. Region 5 – detonation go, 6 – no go.

The influence of ignition location on the DDT in moving flow H_2+O_2 mixture

Investigation of spark plug location on detonation formation was carried out in hydrogen/oxygen mixture. It was found that decrease of the distance between the spark plug and injection block from 150 mm to 100 mm leaded to detonation formation at the distance of

160-175 mm for the time of 140 μs, at the same time at the distance of 150 mm the detonation was formed in the distance approximately 270 mm for the time about 300 μs.

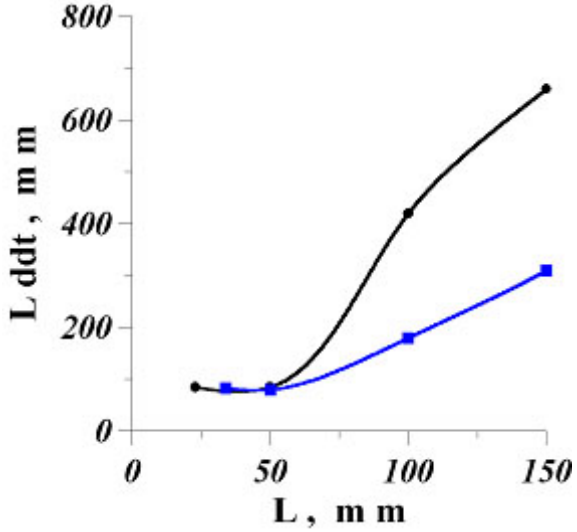

Fig.5. The dependence of deflagration-detonation transition length on the distance from the spark-plug to the detonation chamber closed end

Conclusions

- It is shown that the fuel components mass flow and mixture composition are not constant in the general case of PDE.
- The fuel components mass flow and mixture composition are strongly affect on DDT.
- Turbulization of the fuel components flow by means of the resonator mounted on the injector decreases the ignition delay influence on the DDT.At the Re increase from $5*10^3$ to $55*10^3$ necessary degree of the air enrichment with oxygen for DDT reduces from 65% to 30%.
- At the distance between tube closed end and spark plug reduction from 1.8 to 0.3 tube diameters DDT length reduces monotonously from 3.3 to 1.6 tube diameters.

Acknowledgement

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