HEAT AND MASS TRANSFER IN COMBUSTION PROCESSES

FORMATION OF DETONATION IN A PULSE COMBUSTION CHAMBER WITH A POROUS OBSTACLE

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A study has been made of the influence of a porous obstacle on deflagration-to-detonation transition in a pulse combustion chamber of small length. Dependences of the detonation-wave velocity on the distance have been obtained for two samples of a porous material (steel spheres and a ceramic porous body). It has been shown that the use of an insert from a porous material leads to a reduction of 40% in the predetonation distance without changing substantially the structure of the pulse combustion chamber.

Keywords: deflagration-to-detonation transition, porous obstacle, detonation velocity, thrust.

Introduction. Today’s aircraft and rocket engines whose operation is based on the burning of a chemical fuel at constant pressure (Brighton cycle) or volume (Humphrey cycle) have virtually reached the limit of thermodynamic perfection. One alternative is burning of the fuel in a traveling detonation wave. Due to this, active work is carried out to create a novel class of jet units with the name "pulse detonation engines" (PDEs) as demonstrated by numerous publications [1–6]. Great hopes are placed on the use of detonation combustion in terms of simplifying the structure of an engine and raising its thermodynamic efficiency, raising fuel efficiency, and improving propulsion and other characteristics of an aircraft.

From the viewpoint of thermodynamics, detonation as a physicochemical process occurring with a supersonic rate is virtually similar to the adiabatic process at constant volume and in the absence of heat transfer to the environment. Consequently, engines whose operation is based on detonation combustion are of higher thermodynamic efficiency than existing units [4, 7, 8], which is due to reaching the higher temperatures (by 10 to 20%) and pressures (nearly twice as high) compared to normal combustion in a closed volume.

It is well known [9] that the initiation of detonation of fuel mixtures fired by an electric spark in tubes is preceded by a period of accelerated propagation of the flame, whose length is determined by the time of deflagration-to-detonation transition. We could cite the unacceptably large distances at which deflagration-to-detonation transition is realized and its long duration among the main problems in the way of using detonation in aircraft. A theoretical analysis of the working process of a PDE shows that its operating efficiency determined by such parameters as thrust, the engine’s mass, and cycle frequency can be raised by decreasing the predetonation portion.

One efficient technique of reducing the predetonation distance is to use obstacles of various types. Thus, a technique of reducing predetonation period and distance in a tube by placing profiled regular obstacles in the path of the flame front has been described in [10]. It has been shown that profiled obstacles of a parabolic shape are more efficient for deflagration-to-detonation transition than rectangular ones.

The present work seeks to assess the possibility of accelerating deflagration-to-detonation transition in the case of weak initiation in a pulse combustion chamber (PCCCh) using an obstacle of a porous structure in the path of propagation of the flame front. A mixture of hydrogen with oxygen and air is used as the working medium.
Experimental Setup. Experiments were conducted in a PCCh (Fig. 1) representing a half-open sectional steel tube 1 at whose closed end there was a mixing chamber 2 with three quick-acting valves 3 for feeding hydrogen, oxygen, and air. The mixing chamber 2 had a collection of elements of a special configuration and a cylindrically shaped cavity forming, with the tube 1, a channel of constant cross section $d = 21$ and total length $L = 760$ mm (in what follows, the tube). The PCCh was rigidly fixed on platform 5 and could only move along base 6. The chamber was equipped with a gas panel (Fig. 2) containing a steel casing 1, regulator filters 2, receivers 3, mass flowmeters 4, and manometers 5 and intended to feed the component gases of the fuel mixture and to regulate pressure and their flow rate. A spark plug installed at the end of the mixing chamber was used for ignition of the fuel mixture.