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PHYSICAL CHEMISTRY

Air-Breathing Liquid-Fueled Pulse Detonation Engine Demonstrator

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For the first time, a demonstrator of a new type of air-breathing liquid-fueled engine—a pulse detonation engine—has been designed and tested.

Work on creating a pulse detonation engine is being carried out more and more actively [1, 2]. Such engines operate on a new principle of conversion of the chemical energy of fuel into propulsion, on which fuel is burnt in a traveling detonation wave. In comparison with existing combustion design in air-breathing and jet engines, the detonation combustion of fuel in a traveling wave has a number of fundamental advantages. First, the thermodynamic efficiency of the detonation cycle is much higher than that of other cycles, especially at low pressures in the combustion chamber [3]. Second, a pulse detonation engine can burn both special fuels and ordinary (liquid) jet propulsion fuels. Third, unlike many existing jet engines, a pulse detonation engine has a simple design (requires no expensive compressors or turbopumps) and is reliable (has no moving elements) and self-sufficient (needs no boosters to reach the operation mode). Finally, using the multitube design of a pulse detonation engine allows one to improve the thrust performance by simply increasing the number of chambers. Inasmuch as the practical implementation of detonation combustion of fuel saves energy resources, stationary power plants operating on this principle are also being developed.

The demonstrator has a two-circuit design with continuous air and fuel supply (Fig. 1) and has been developed on the basis of the results of our previous studies [4–6]. The first circuit is a 1-m-long tube 28 mm in diameter. Full-flow air-assist atomizer *1* for fine atomization of liquid fuel (to a drop size of 10–15 μm) and electric discharger ED1 for periodic ignition of a drop fuel–air mixture are located at one end of the tube. The other end of the tube is connected through conical transition section *5* to a tube 41 mm in diameter, which is inserted into straight tube *6* (52 mm in diameter) of the second circuit. In the second circuit, air is supplied with low-head centrifugal compressor *11* and liquid fuel is fed with standard low-pressure automobile fuel injector *10*. The open end of the second circuit is equipped with a nozzle (which is not shown in Fig. 1). The total length of the demonstrator is 1.8 m. The fuel in both circuits in demonstration experiments is a primary reference hydrocarbon, *n*-hexane or *n*-heptane. The fuel and air in the experiments are at room temperature. The demonstrator is suspended by steel cables from the ceiling of an explosion chamber for measuring the jet thrust by the ballistic pendulum method.

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The first circuit serves to periodically initiate detonation in the fuel–air mixture and transfer a detonation wave into the second circuit. To facilitate detonation initiation, the first discharger is followed by 460-mm-long Shchelkin spiral *2*, wound from a steel wire 4 mm in diameter at a pitch of 18 mm. Downstream of the tube section with the Shchelkin spiral is an additional element in the shape of tube coil *3* of a length (along the axis) of 365 mm. The tube coil favors the gasdynamic focusing of compression waves generated by the accelerating flame [6]. The focusing element is followed by the second discharger, ED2, which generates an electric discharge at the moment the blast wave arrives at its electrodes; thereby, ED2 initiates detonation in each cycle according to a recently described mechanism [4, 5]. The synchronization of the triggering of the second discharger with the arrival of the blast wave is performed with ionization probe *4*. Conical transition section *5* is used to reliably transfer the detonation wave. The detonation wave travels along the tube of the second circuit and passes to the atmosphere through the nozzle, thus imparting a jet thrust to the demonstrator.

The demonstrator was triggered as follows. Initially, a voltage was applied at a frequency of 2 Hz to standard car spark plug ED3 in the second circuit (Fig. 1). Then, air and fuel were fed to the second circuit. After the fuel–air mixture was ignited, there was steady-state diffusion combustion in the second circuit, which caused heating of the tube wall. When the wall temperature reached 50°C, air and fuel were supplied to the first circuit; spark plug ED3 was switched off; and, by activating discharger ED1 at the given frequency, the operation mode of periodic combustion of the fuel–air mixture in the traveling detonation wave was attained. All

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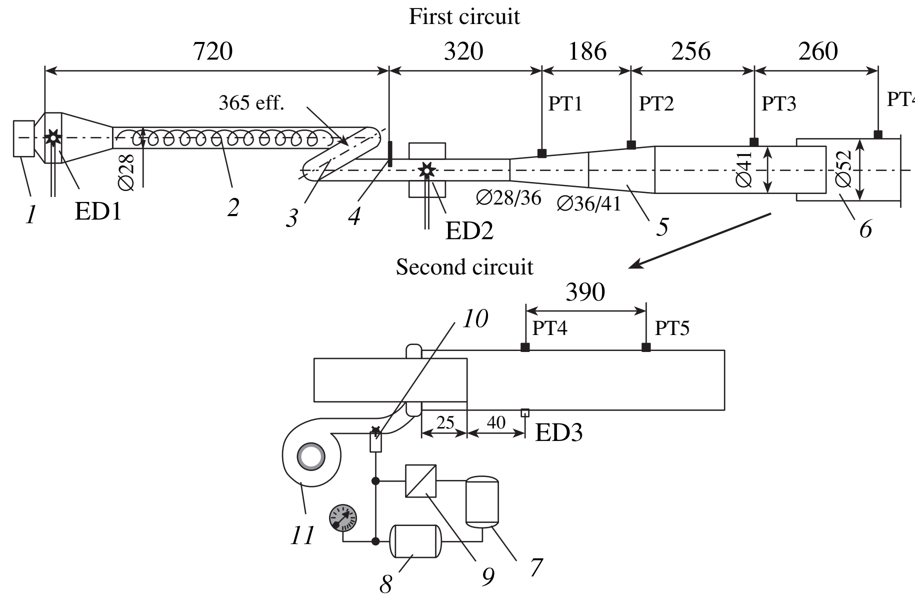

Fig. 1. Two-circuit pulse detonation engine demonstrator: (*1*) air-assist atomizer, (*2*) Shchelkin spiral, (*3*) tube coil, (*4*) ionization probe, (*5*) conical transition section, (*6*) second-circuit tube, (*7*) second-circuit fuel tank, (*8*) fuel pump, (*9*) fuel valve, (*10*) atomizer, and (*11*) compressor. The sizes are given in millimeters.

the steps of starting the pulse detonation engine and attaining the operation mode were controlled by a digital controller. During the operation of the demonstrator, we recorded the air and fuel flow rates in the first and second circuits, the discharge current in dischargers ED1 and ED2, and the dynamics of wave processes using piezoelectric pressure transducers PT1–PT5 (Fig. 1).

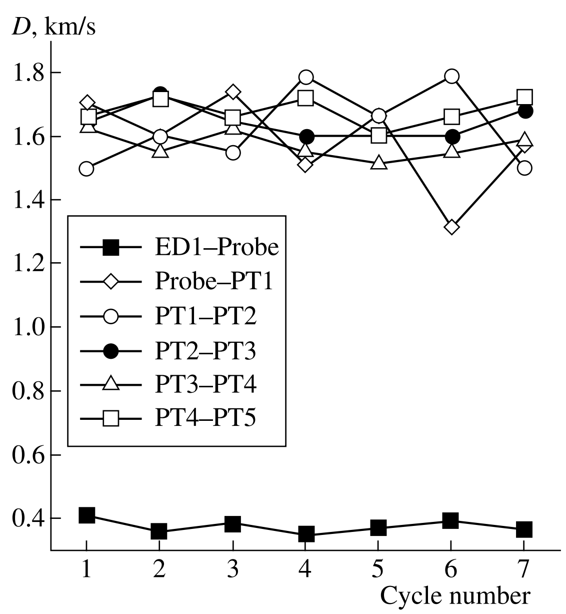

Fig. 2. Blast wave velocities *D* measured at various measurement segments in the first and second circuits during the operation of the demonstrator in the detonation mode at a pulse repetition frequency of 2.2 Hz.

In the detonation mode, the fuel and air flow rates measured in the first circuit were 0.4 ± 0.1 and 6.7 ± 0.5 g/s, respectively, and in the second circuit, 3.8 ± 0.1 and 60 ± 7 g/s, respectively. The minimal energy required to initiate detonation in the first circuit is 30 J per cycle. Taking into account that the efficiency of the electric dischargers used was 15–20%, one can expect that the use of other, more efficient igniters will further allow one to decrease the initiation energy to several joules per cycle.

Figure 2 presents the blast wave velocities measured at various measurement segments in the first and second circuits during the operation of the demonstrator in the detonation mode at a pulse repetition frequency of 2.2 Hz. The measurements were made between the discharger and the probe (ED1–Probe), between the probe and pressure transducer PT1 (Probe–PT1), between transducers PT1 and PT2 (PT1–PT2), between transducers PT2 and PT3 (PT2–PT3), between transducers PT3 and PT4 (PT3–PT4), and between transducers PT4 and PT5 (PT4–PT5). It is seen that, in all the cycles, detonation in the first circuit emerged downstream of the second discharger and propagated at an average velocity of 1600–1700 m/s. In the second circuit, the detonation wave traveled at the same velocity. Note that, in the case of detonation initiation failure, e.g., because of a failure of discharger ED2, the velocity along the probe–PT1 measurement segment decreased to 1000–1200 m/s.

The jet thrust was measured during the operation of the demonstrator at generation frequencies of 2.2, 3.1, and 3.9 Hz. Figure 3 presents the measured thrust versus frequency. The thrust of the pulse detonation engine

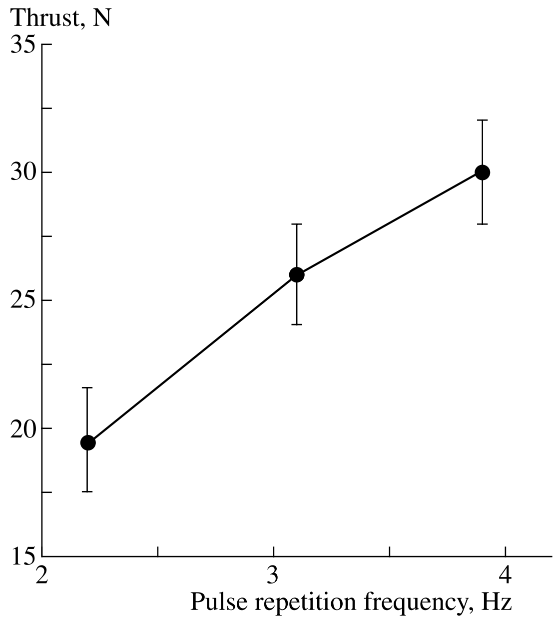

Fig. 3. Measured jet thrust versus pulse repetition frequency.

is seen to increase linearly with frequency. The maximal measured thrust was 30 ± 2 N. The maximal achieved demonstrator operation frequency was 8 Hz.

Thus, for the first time, we have designed and tested a demonstrator of a two-circuit air-breathing liquid hydrocarbon–fueled pulse detonation engine. Unlike the existing design of two-circuit pulse detonation engines, in which a detonation wave in the first circuit is initiated using a fuel–oxygen mixture, the demonstrator exhibits stable operation with periodic detonation without using oxygen. Owing to acceptable weight and size characteristics of the demonstrator, the proposed process design can be regarded as promising for practical applications. The main problem to be solved is to ensure the stable operation of a pulse detonation engine that burns not highly volatile fuel (*n*-hexane or *n*-heptane) but low-volatility fuel of the type of aviation kerosene.

REFERENCES

1. Frolov, S.M., *Tyazh. Mashinostr.*, 2003, no. 9, pp. 19–22.
2. Roy, G.D., Frolov, S.M., Borisov, A.A., and Netzer, D.W., *Progr. Energy Combust. Sci.*, 2004, vol. 30, no. 6, pp. 545–672.
3. Frolov, S.M., Barykin, A.E., and Borisov, A.A., *Khim. Fiz.*, 2004, vol. 23, no. 3, pp. 17–25.
4. Frolov, S.M., Basevich, V.Ya., Aksenov, V.S., and Polikhov, S.A., *Dokl. Akad. Nauk*, 2004, vol. 394, no. 2, pp. 222–224 [*Dokl. Phys. Chem.* (Engl. Transl.), vol. 394, part 1, pp. 16–18].
5. Frolov, S.M., Basevich, V.Ya., Aksenov, V.S., and Polikhov, S.A., *Dokl. Akad. Nauk*, 2004, vol. 394, no. 4, pp. 503–505 [*Dokl. Phys. Chem.* (Engl. Transl.), vol. 394, part 2, pp. 39–41].
6. Frolov, S.M., Basevich, V.Ya., and Aksenov, V.S., in *Application of Detonation to Propulsion*, Roy, G., Frolov, S., and Shepherd, J., Eds., Moscow: Torus Press, 2004, pp. 240–249.